



Yasri, Pratchayapong (2014) *Views of the relationship between science and religion and their implications for student learning of evolutionary biology*. PhD thesis.

1 publication resulting from this thesis should be cited using the DOI link below:

Yasri, P., Arthur, S., Smith, M.U. *et al.* *Relating Science and Religion: An Ontology of Taxonomies and Development of a Research Tool for Identifying Individual Views*. *Sci & Educ* **22**, 2679–2707 (2013). <https://doi.org/10.1007/s11191-013-9623-4>

<http://theses.gla.ac.uk/5082/>

Copyright and moral rights for this work are retained by the author

A copy can be downloaded for personal non-commercial research or study, without prior permission or charge

This work cannot be reproduced or quoted extensively from without first obtaining permission in writing from the author

The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the author

When referring to this work, full bibliographic details including the author, title, awarding institution and date of the thesis must be given

Enlighten: Theses
<https://theses.gla.ac.uk/>
research-enlighten@glasgow.ac.uk



**VIEWS OF THE RELATIONSHIP BETWEEN SCIENCE AND RELIGION
AND THEIR IMPLICATIONS FOR STUDENT LEARNING OF
EVOLUTIONARY BIOLOGY**

Pratchayapong Yasri

Thesis presented for the Degree of Doctor of Philosophy

School of Education
College of Social Sciences
University of Glasgow

March 2014

ABSTRACT

Studies have shown that many students perceive clashes between scientific and religious perspectives which contribute to negative impacts on student learning of evolution. Much earlier work, at least in larger-scale studies, investigates the influence of these perspectives in the form of a binary classification of the relationship between the two (either science or religion, either biological evolution or biblical creation, either accept or reject evolution). This PhD study therefore aims to develop a new set of research tools employing multidimensional classifications of the relationships and use these to explore four facets of student learning. These consist of views of the relationship between science and religion, justifications for levels of acceptance of evolution, positions on the relationship between biological evolution and biblical creation, and conceptions of biological evolution and the nature of science in relation to the positions. In order to understand the diversity of patterns of responses, a survey-based study using a questionnaire was conducted among 327 high school students in a religiously heterogeneous context, Thailand. The study shows that, rather than subscribing to simple incompatible views, these students tended to hold compatible views of the relationship between science and religion, some form of reconciliatory position on the relationship between biological evolution and biblical creation, and intermediate levels of acceptance of evolution. In addition, it shows that those accepting evolution tended to rely on science or refuse religion as a cognitive authority; whereas, those not accepting evolution tended to rely on religion or refuse science as a cognitive authority. Furthermore, it demonstrates that many students had developed their scientific sophistication and acceptance of evolution without changing their religious beliefs through changes in their understanding of the evidence for evolution and in their view on the relationship between science and religion. However, the study also shows that those holding reconciliatory positions on the relationship between biological evolution and biblical creation tended to hold a wide range of misconceptions about evolution and the nature of science. I therefore suggest that teachers should be aware of the roles of scientific and religious perspectives in learning about evolution as well as the diversity of ways for relating them positively in the hope that this understanding would help them enhance student learning of evolution.

Table of contents

Chapter 1 Introduction to this thesis.....	1
Chapter 2 Worldviews in Evolution Education	13
Chapter 3 Research Methods	35
Chapter 4 Views of the relationship between science and religion	50
Chapter 5 Student acceptance of biological evolution	90
Chapter 6 Student positions of the origin of life and biodiversity	146
Chapter 7 Student misconceptions of biological evolution	191
Chapter 8 Overall Discussion, Implications and Conclusion.....	231

Detailed table of contents

Chapter 1 Introduction to this thesis.....	1
1.1 The structure of this thesis.....	3
1.2 The main contributions of this thesis	6
1.3 The significance of this thesis.....	9
Chapter 2 Worldviews in Evolution Education	13
2.1 Introduction to evolution education.....	13
2.2 The origin of the issue of the origins.....	15
2.2.1 Religious explanations: creation narratives	16
2.2.2 Scientific explanations: abiogenesis and evolution	17
2.2.3 Possible contradictions between the two sets of explanations.....	19
2.3 Worldviews and evolution education.....	20
2.3.1 Religious worldviews.....	22
2.3.2 Naturalistic worldviews	24
2.3.3 Religio-naturalistic worldviews	26
2.4 Research gaps and an overarching research question	27
Chapter 3 Research Methods	35
3.1 Justification of the research methods	35
3.2 Development of the questionnaire	36
3.2.1 Construction of the research tools in the questionnaire	38
3.2.2 Refinement of the questionnaire	39
3.2.3 Ethical approval of the questionnaire.....	40
3.2.4 Translation of the questionnaire.....	40
3.3 Pilot study of the questionnaire	42
3.4 Participants	43
3.4.1 The participating school	43
3.4.2 Student participants	45
3.5 Data collection	46
3.6 Ethical considerations	48
Chapter 4 Views of the relationship between science and religion	50
4.1 Introduction.....	51
4.2 Taxonomies of views for relating science and religion	53

4.3	Comparison and synthesis of taxonomies.....	55
4.3.1	Polkinghorne (1986).....	56
4.3.2	Barbour (1990).....	58
4.3.3	Haught (1995).....	61
4.3.4	Nord (1999).....	64
4.3.5	Alexander (2007)	65
4.4	Synthesis of taxonomies in the philosophical literature.....	68
4.5	Reanalysis of views in empirical studies	72
4.6	Development of a research tool	76
4.7	Usefulness, Reliability and Validity of <i>SRSII</i>	78
4.8	Considerations for Future Studies	83
4.9	Conclusion.....	85
4.10	Summary	88
Chapter 5 Student acceptance of biological evolution		90
5.1	Acceptance of evolution	91
5.2	Levels of student acceptance of evolution.....	93
5.2.1	Quasi-continuous scales of student acceptance of evolution.....	94
5.2.2	Binary categories of student acceptance of evolution.....	97
5.2.3	Ternary categories of student acceptance of evolution.....	98
5.2.4	Multi-dimensional categories of student acceptance of evolution	100
5.2.5	The preferred categorical levels of acceptance of evolution	101
5.3	Justifications for levels of acceptance.....	102
5.3.1	Justifications for acceptance based on pre-defined reasons	103
5.3.2	Justifications for acceptance in qualitative studies	105
5.3.3	Summary of student justifications for acceptance of evolution ..	107
5.4	Cognitive authority	108
5.4.1	Science as a cognitive authority	110
5.4.2	Religion as a cognitive authority.....	113
5.5	Research justification and questions.....	115
5.6	Research methods.....	117
5.6.1	Data collection	117
5.6.2	Data analysis	118
5.7	Findings.....	120
5.7.1	Student acceptance of biological evolution.....	120

5.7.2	Student justifications for levels of acceptance of biological evolution.....	122
5.8	Discussion	135
5.8.1	Different levels of student acceptance of biological evolution ...	135
5.8.2	Different forms of cognitive authority influencing student justifications for levels of acceptance of biological evolution.....	137
5.9	Conclusion.....	144
Chapter 6 Student positions of the origin of life and biodiversity		146
6.1	Why study positions on the origin of life and biodiversity	147
6.2	Positions of the origin of life and biodiversity	148
6.2.1	Creationism	152
6.2.2	Divine evolution	153
6.2.3	Nontheistic evolution.....	155
6.3	Changes in positions of the origin of life and biodiversity	157
6.4	Previous studies on student changes in positions	158
6.5	Reasons for student changes in the positions.....	162
6.6	Rationale and purpose of this study.....	164
6.7	Research method.....	166
6.7.1	Student and school participants	166
6.7.2	Data collection	168
6.7.3	Data analysis.....	168
6.8	Findings.....	169
6.8.1	Student positions on the origin of life and biodiversity	169
6.8.2	Student changes in positions of the origin of life and biodiversity	172
6.8.3	Student reasons for changes in position	177
6.8.4	Correlations of magnitude of change and reasons for changing...	178
6.9	Discussion	180
6.9.1	Distribution of student positions on the origin of life and biodiversity	180
6.9.2	Student changes in position of the origin of life and biodiversity	182
6.9.3	Student reasons for changing position	186
6.10	Conclusion	189
Chapter 7 Student misconceptions of biological evolution		191
7.2.1	Synthesised classification of misconceptions	195

7.2.6 Vernacular misconceptions	204
7.5.2 Common misconceptions about biological evolution.....	213
7.6.1 Shared common misconceptions	222
7.6.2 Group-specific misconceptions.....	225
7.7 Conclusion.....	230
Chapter 8 Overall Discussion, Implications and Conclusion.....	231
8.1 Summary of the main findings.....	231
8.2 Links between the four constructs in this study.....	234
8.3 Limitations	240
8.4 Practical implications	240
8.5 Conclusion.....	244

List of appendices

Appendix A: The Science-Religion Self-Identification Inventory (SRSII).....	255
Appendix B: Acceptance of Biological Evolution Measurement (ABEM)	256
Appendix C: The Creation-Evolution Self-Identification Inventory (CESII).....	257
Appendix D: The Measure for Understanding of Science and Evolution (MUSE)	259
Appendix E: A formal letter sent to the school participant	263
Appendix F: Plain Language Statement.....	264
Appendix G: Dichotomous key for identifying the relationship between science and religion.....	266
Appendix H: Student levels of agreement on the different views of the relationship between science and religion (N = 327).....	267
Appendix I: The key for scoring student responses to MUSE (all incorrect items are crossed out).....	268
Appendix J: License Agreement between the author and Springer.....	272

List of Tables

Table 4.1: Summary of views discussed in the philosophical literature, with descriptions.....	67
Table 4.2: Summary of selected view labels in the proposed empirically-oriented taxonomy, with descriptions.	78
Table 4.3: Characteristics of study samples	79
Table 4.4: Summary of preferred views (based on the single item “preferred view” selection) among the three samples	80
Table 4.5: Alternative statements provided by Thai participants	81
Table 5.1: Summary of previous studies on categories of acceptance of evolution	96
Table 5.2: Aspects of the nature of science with descriptions, originally contributed by Abd-El-Khalick (2012, p.356-357).....	111
Table 5.3: Final template for coding student justifications for levels of acceptance of evolution	119
Table 6.1: Positions on the origin of life and biodiversity in the literature and in this study	151
Table 6.2: Positions of the origin of life and biodiversity, with descriptions used in the empirical study described here.....	154
Table 6.3: Characteristics of student sample.....	166
Table 6.4: Student positions on the origin of life and biodiversity	170
Table 6.5: Student positions of the origin of life and biodiversity in relation to grades	172
Table 6.6: Student changes in positions of the relationship between creationist and evolutionist explanations regarding the origin of life and biodiversity (positions taken before the course are in rows; and positions taken after in columns)	176
Table 6.7: Student reasons for changing in the positions.....	177
Table 6.8: Student changes in position in relation to the number of reasons .	180
Table 7.1: Classifications of misconceptions about biological evolution	197
Table 7.2: Summary of misconceptions and fundamental concepts of biological evolution and the nature of science related to evolution, derived and	

simplified from Smith (2010b). This forms the framework for the scoring of the tool. However, elements in this table may relate to more than one item in the tool itself.	201
Table 7.3: Student participants classified by their preferred position on the origin of life and biodiversity	207
Table 7.4: Complete statements in the <i>Measure for Understanding of Science and Evolution (MUSE)</i> , correct phrases are in bold.....	211
Table 7.5: Mean numbers of student misconceptions and standard deviations in conjunction with student positions of the origin of life and biodiversity .	212
Table 7.6: Common misconceptions about evolution among the full group of student participants, with facility values.....	214
Table 7.7: Specific misconceptions of evolution among the student participants in the different groups, with facility values calculated for the relevant group	216
Table 7.8: Main difficulty of each group of misconception	225

List of figures

Figure 2.1 Summary of four strands of research focused in this PhD thesis.....	31
Figure 4.1: Summary of the correspondence between published views on the relationship between and religion. Category names used in this paper are shown in bold and corresponding views from other work are provided below the category names. Citations labeled 1-6 are taken from the philosophical literature and a-d from the educational literature. (1 = Polkinghorne (1986), 2 = Barbour (1990), 3 = Haught (1995), 4 = Nord (1999), 5 = Alexander (2007), a = Yasri and Mancy (2012), b = Taber et al., (2011), c = Shipman et al. (2002) and d = Hokayem & BouJaoude (2008). (STR = science trumps religion; RTS = religion trumps science; SSR = science supports religion; RSS = religion supports science)	71
Figure 4.2: Classification of views of the relationship between science and religion. Grey-shaded views are explicitly included in the empirically-oriented taxonomy. (STR = science trumps religion; RTS = religion trumps science; SSR = science supports religion; RSS = religion supports science) .	75
Figure 5.1: Levels of student acceptance of biological evolution	120
Figure 5.2: Student acceptance of biological evolution in relation to religious beliefs (Buddhist students = 217, Theistic students = 97, Others = 12) ...	121
Figure 5.3: Summary of student justifications for levels of acceptance of biological evolution (CA = cognitive authority and NOS = the nature of science)	123
Figure 5.4: Student justifications for accepting and not accepting evolution. Sub-elements of NOS and pseudo-NOS are shown with bullet points.	139
Figure 6.1: The spectrum of positions of the origin of life and biodiversity ...	155
Figure 6.2: Distribution of positions on the origin of life and biodiversity, compared between Christian and Buddhist students.....	170
Figure 7.1: Classification of student participants	208
Figure 7.2: The total number of possible misconceptions in each category was: common-sense = 4; content = 21; NOS = 34; Non-science = 4; vernacular = 6)	213

Figure 7.3: the full distribution of facility values for the different items, split by group	219
Figure 7.4: the full distribution of facility values for the different items, split by group	220
Figure 7.5: the full distribution of facility values for the different items, split by group	221
Figure 8.1: Possible links between the constructs in this study.....	235

Acknowledgements

I am most indebted to Dr Rebecca Mancy from the University of Glasgow who effectively supervised my work throughout the entire PhD and kindly supported me in many ways. I also thank Leon Robinson from the University of Glasgow and Prof Micahel Reiss from the University of London for their constructive and insightful suggestions. I also take this opportunity to thank Prof Mike Smith from Mercer University, USA, who enthusiastically reviewed Chapter 4 of my thesis, as well as Dr Shagufta Arthur who conducted data collection in the UK and Pakistan and allowed me to use her data for the analysis in the Chapter. I also give my thanks to the Thai Government for the financial support throughout this study.

But this thesis would not have been possible without the student participants whose responses were informative and interesting, as well as the teachers of the participating school who kindly assisted me and made my data collection so convenient. So I want to express my appreciation to them here.

I will not forget the continuous support received from the School of Education, both from academic, administrative, technical and support staff, and other PhD students, especially Amina Kamando, Alexia Koletsou, Jaime Earnest, Renato Margiotta and Keneilwe Molosi-France, among others who have been through this pleasant journey together. Last but not least, I turn towards my family and friends to express my thankfulness and deep gratitude for their encouragements given to me constantly.

Author's declaration

I declare that this thesis does not include work forming part of a thesis presented successfully for another degree. This thesis represents my own work except where referenced to others.

Name: Pratchayapong Yasri

Date 28 March 2014

Reg.No: 0711836y

Place: University of Glasgow

Prologue

This PhD thesis originated from my “difficult time” during my undergraduate years (2002-2006). I was reading biology as my first degree because I was really interested in the natural mechanisms of life. Meanwhile, I was also reading the Bible as my “first authority” because I fully entrusted its guidance for my life. However, at that time, these two “books” somehow drove me to a difficult situation in which I felt that I had to accept one and reject the other.

Of course, as a part of the degree in Biology, I had to undertake a course on evolution. In the first lecture of the course, I did not feel warmly welcomed at all as the lecturer started the very first slide by pointing out a few “misconceptions” about evolution and one of which was belief in God. Although this was the only time she mentioned something associated with religious beliefs, it remained constantly in my mind throughout her following lectures which mainly addressed aspects of macroevolution. Perhaps it was a coincidence that one topic taught at a Sunday-school class during that time was God’s creation in the book of Genesis. Although I had read and heard about this biblical account several times, clashes between evolution and creation were strongly triggered at that particular moment. Indeed, taking the literal word of the Bible as the priority, I decided to study evolution only for passing an exam without fully accepting it.

Soon after that, another lecturer took over the second half of the course which particularly addressed aspects of microevolution. Interestingly, he began his lecture by a very thoughtful explanation that evolutionary theory explains natural processes causing the emergence and development of the diversity of life forms throughout a very long period of time; and thus it has no concern with religious belief. Of course, I was immediately drawn back to the course again and found it much more interesting. The story continued as another coincidence subsequently happened. Another Sunday-school teacher explained, in fact, that there are different ways in which Christians and theological scholars interpret the biblical account of God’s creation in Genesis. One of the examples that she showed was a poetic interpretation according to ancient Hebrew literature.

Confusion, of course, was my result after being exposed to these different views given by different people. However, through learning evolution based on the paradigm suggested by the second lecturer and reading the Bible according to the suggestion from the second Sunday-school teacher, I became more comfortable in holding the Christian faith alongside learning biology. The tension seemed to be resolved and the two identities of mine (i.e. religious and scientific) remained secure. I came to realise that evolution need not harm Christian belief if one understands the nature of the theory of evolution appropriately. Indeed, interpreting the Bible in the way that (I believe) it should be interpreted, an internal contexts-based approach, one should realise the scriptures do not necessarily contradict the scientific explanations of the origin of biodiversity.

Motivated by this clarity, I decided to enrich my understanding of the nature of science by pursuing a Master's degree in molecular biology and genetics in 2006. Throughout this study, I became even more confident that I did not have to take off my lab coat before going to church; and of course, there was no need for me to close the Bible before opening laboratory manuals. I could be religious as well as scientific at the same time. Later on, I was determined to explore the journey of "faith in religion" and "fact in science" more academically and hoped to pass on my experience in the compatibility between science and religion to others who may be in the midst of a similar "difficult time". Being driven by the idea that evolution can be taught without threatening religious beliefs, and the idea that religious believers can view the relationship between science and religion in a positive dimension if this is communicated appropriately, I therefore came to the University of Glasgow in 2008 to study for another Master's degree in Inter-professional Science Education and Communication (IPSEC) in which I conducted a qualitative study (MSc dissertation) entitled *Perceptions of the relationship between evolutionary theory and biblical explanations of the origins of life and their effects on the learning of evolution among high school students*. Building on my interest from this, I carried on working on this topic for my PhD which aims to elaborate the research topic in greater detail.

Chapter 1

Introduction to this thesis

Research studies in a range of countries have shown that many students struggle with learning about evolution, conceptually but also emotionally (Brem et al., 2003, Clores and Limjap, 2006, Dagher and BouJaoude, 2005, Donnelly et al., 2009, Fulljames et al., 1991, Hokayem and BouJaoude, 2008, Taber et al., 2011, Woods and Scharmann, 2001, Yasri and Mancy, 2012). Some of these difficulties are due to perceived clashes between evolutionary science and religious explanations of the origins of life and biodiversity. In this thesis, I seek to understand different facets of student learning about evolutionary biology and how these relate to their understandings of both religious and scientific explanations.

This thesis can be thought of as an extension of my previous MSc dissertation conducted during 2008 and 2009 (later published in Yasri and Mancy (2012) in the *International Journal of Science Education* in 2012). In this study, based on interviews with nine high school students in Thailand, different views of the relationship between science and religion are distinguished, corresponding to different learning approaches to biological evolution, resulting in different ways in which students perceive and accept biological evolution (Yasri and Mancy, 2012). In the course of this project, further interesting questions arose. First, are these views prevalent in a larger group of student sample and how are they discussed in other literature? A second question is concerned with how do science and religion influence different levels of student acceptance of biological evolution and how students justify the levels of acceptance through scientific and religious perspectives? Third, what kinds of relationship do students perceive if the focus of the relationship is explicitly changed from science and religion (focused in the first question) to evolutionary theory and biblical accounts of divine creation instead? Fourth and final, how do students

holding different positions of the relationship between evolution and creation understand biological evolution?

These four questions contribute to four aspects investigated in this PhD thesis: (1) student *views* of the relationship between science and religion, discussed theoretically in more depth based on the philosophical and educational literature, and explored empirically among a larger group of student sample; (2) student *justifications* for accepting or not accepting biological evolution and their source in the form of “cognitive authority”, in relation to scientific and religious perspectives (Wilson, 1983); (3) student *positions* on the relationship between evolution and creation in the form of the question of the origin of life and biodiversity; and (4) student *misconceptions* of biological evolution in relation to positions on the origin of life and biodiversity. Please note that the terms in italics are the keywords deliberately used throughout this thesis.

By understanding these specific aspects of the interrelationship between the religious and scientific perspectives, it is hoped that science educators and biology teachers would be able to deal with issues concerning different views of the relationship between evolutionary theory and religious beliefs in classrooms more effectively (Reiss, 2008, Reiss, 2009b). The rationale for including these four aspects in the context of evolution education is taken from Evans (2008) who points out that students come to biology classes with their own preconceptions about the world in general and sometimes also evolution in particular. These preconceptions can either enhance or hinder student learning of the theory of evolution in a number of ways. Mahner and Bunge (1996) claim that preconceptions that hinder the learning appear to be in the form of religious beliefs nurtured by religious education. However, Hokayem and BouJaoude (2008) suggest that science teachers should not treat religious beliefs as misconceptions about evolution. In contrast, religious beliefs should be viewed as worldviews. Furthermore, Sinatra et al. (2008, p. 189) point out that learning about evolution is not simply a matter of content presentation by teachers or knowledge acquisition by students themselves, but a conceptual reformulation in which learners need “to see the world in new and different ways”. A similar suggestion is made by Hokayem and BouJaoude (2008, p. 414)

who explain that teaching the theory of evolution to students who are committed to religious beliefs is (or should be) an act of helping students to wear “different glasses to gain another perspective” not the reformulation of student worldview in the sense of religious conversion. This thesis is therefore entitled *Views of the relationship between science and religion and their implications for evolutionary biology* in which the four aspects explained in the previous paragraph are examined. The following section explains how this thesis is structured.

1.1 The structure of this thesis

Besides this current chapter, there are other seven chapters which form this thesis. Developing the theme of the importance of student views of the relationship between science and religion and their implications for biological evolution, Chapter 2 presents the general background of evolution education research, current issues surrounding this subject and particularly the question of the origin of life and biodiversity, as well as discussing influences of religious and naturalistic worldviews on student learning of evolution. The chapter ends by highlighting current research gaps and drawing out the importance of the four aspects of the interrelationship between the religious and scientific perspectives.

In order to investigate these four aspects, Chapter 3 explains how this study is conducted through a large-scale survey based on a newly developed questionnaire using both quantitative and qualitative research approaches in Thailand with participants who were primarily Buddhists and Christians. It also provides the rationale for using this research method. In addition, it discusses how questions in the questionnaire were developed based on previous empirical studies, as well as philosophical literature, and how the questionnaire itself was validated, translated and piloted before being administered. The recruitment of the school and student participants is also explained in the chapter. In addition, it presents how this PhD study is carried out under the consideration of ethics in educational research.

The four following chapters consist of separate empirical studies that can be read independently. However, when combined, they provide the evidence that constitutes the main contributions of this thesis. The purpose of the combination of the evidence is to explore the implications of learner understandings of the relationship between religious and scientific perspectives for student learning about evolution. Each of these chapters relates to one of the four factors outlined above. Each chapter is presented in the format of a journal article or manuscript consisting of its own literature review identifying specific research gaps, justification of the questions of interest, analytical methods used including the development of a new research tool, findings, discussion, implications and conclusion. Therefore, this thesis is not a monograph but consists of four separate studies; however, these studies are linked and all contribute to the main aim of this thesis.

More specifically, Chapter 4 focuses on student *views* of the relationship between science and religion. It compares and synthesises different taxonomies of views of the relationship proposed in educational and philosophical literature in order to develop a synthesised taxonomy which is used as a framework to develop a new research tool assessing student views of the relationship between science and religion. It also shows the distribution of the number of students holding the different views, ranging from incompatible to compatible views. However, the majority of student participants preferred the compatible to the incompatible views.

Chapter 5 focuses on different levels of acceptance of biological evolution (strongly accept, accept with reservation, unsure, reject some parts, and strongly reject) selected by student participants, and their *justifications* for those levels of acceptance. It shows that student acceptance of biological evolution is not binary. Those accepting evolution tend not to strongly accept it but hold some reservations, whereas those rejecting evolution tend to reject only some parts of the theory of evolution rather than the whole. In addition, written responses show that student justifications for accepting evolution are associated with reliance on science as cognitive authority through the *nature of science (NOS)*, the (de facto) *acceptance of scientific claims* and/or *faith in*

science, or refusal of religion as a cognitive authority. In contrast, student justifications for being unsure or rejecting evolution are associated with reliance on religion as a cognitive authority, or refusal of science as a cognitive authority through *pseudo-NOS*, *rejection of scientific claims*, and/or *mistrust of science*.

Chapter 6 emphasises student *positions* on the relationship between biological evolution and biblical creation in respect to the question of the origin of life and biodiversity. In this chapter, a spectrum of positions on the origin of life and biodiversity is developed based on previous empirical as well as philosophical studies which is used as a research tool assessing student positions as well as changes in position. It shows that student participants held a range of different positions on the origin of life and biodiversity from literal creationism to atheistic evolution. It also shows that about 70% of the student participants who took a course on evolution changed their position after taking the course. In addition, it points to possible factors to which students attributed changes in position: understanding of evolutionary evidence and the relationship between science and religion.

Chapter 7 considers whether student participants holding different positions on the origin of life and biodiversity (i.e. creationism, divine evolution and non-theistic evolution) tend to demonstrate different patterns of *misconceptions* of biological evolution and the nature of science related to evolutionary theory. It demonstrates that the students in this sample held a number of shared common misconceptions ranging from common-sense, content-based and NOS-based to vernacular misconceptions. Some misconceptions were shared by all groups, but each group also tended to be associated with specific misconceptions about biological evolution and the nature of science. Among the whole sample, those holding the divine evolution position demonstrated the largest number of common misconceptions, even though, on average, each individual held fewer misconceptions.

Finally, Chapter 8 sums up the main findings from each of the four empirical chapters and draws possible connections among them to explain the implications

of views of the relationship between science and religion for student learning of biological evolution. In addition, it highlights some implications for educational practices as well as suggestions for further studies.

1.2 The main contributions of this thesis

This PhD thesis contributes to the research community both new findings contributing to deeper theoretical understandings of the implications of science and religion for student learning of biological evolution, and four research instruments (two new and two modified) eliciting student *views* on the relationship between science and religion, student acceptance and *justifications* for accepting or not accepting evolution, *positions* on the origin of life and biodiversity, and *misconceptions* about biological evolution and relevant aspects of the nature of science. The findings themselves are described in the previous section; in this section I emphasise how these constitute new knowledge, linking each aspect back to the relationship between science and religion. I then provide more details regarding the research tools.

In terms of findings, the work contributes in four main areas. Yasri and Mancy (2012) show that student learning of biological evolution is associated with student views of the relationship between science and religion based on interviews with nine high school students. The present study continues to explore implications of *views* of the relationship between science and religion for the learning about evolution in a larger sample by extending data collection to a large number of students (N = 327) in a Christian school in Thailand. Thus, this study provides the first large-scale findings relating to student views of the relationship between science and religion and positions of the origin of life and biodiversity based on a Christian setting in a Buddhist society. This heterogeneous context contributes to existing knowledge as studies to date have been mainly conducted in Western contexts. It shows that the students hold a range of views of the relationship between science and religion; however, the majority tend to prefer one of the views in which science and religion are considered compatible.

The second study, reported in Chapter 5, is based on the idea that perceptions of science and religion and the relationship between them are likely to contribute to acceptance of evolutionary theory. I explore acceptance using a new tool and investigate reasons for acceptance using the framework of cognitive authority. Previous research on acceptance is common; however, acceptance is usually investigated as a binary construct whereas here I incorporate two additional levels: “accept with reservations” and “reject some parts”. Previous research on justifications for levels of acceptance is scarcer, and participants have typically been asked to select reasons from pre-defined categories with little acknowledgement of theoretical frameworks guiding these. This research shows that additional insight can be gained from using an open-ended format, and that the framework of cognitive authority can be applied productively to assist our understanding of *justifications*. Specifically, I show that those who tend to accept evolution rely on science or refusing religion as a cognitive authority, whereas those who reject tend to rely on religion or refusing science as a cognitive authority. The relative roles of these different justifications, as well as the tendency to refer to particular aspects of science and religion, have not been reported previously.

In Chapter 6, I assume that views of the relationship between science and religion would contribute to determining how students perceive the relationship between biological evolution (as a subset of science) and biblical creation (as a subset of religion), leading to the formation of different *positions* on the origin of life and biodiversity. Although the positions of this type have been investigated in the past, this study includes a larger range of positions than any existing work, and like only one previous study, investigates positions before and after taking a course on evolution. This study shows that among this sample, the distribution is fairly polarised before taking the course on evolution (i.e. either creationist or atheistic evolutionist positions are selected). However, after taking the course, the distribution tends to be towards reconciliatory positions, of which agnostic evolution is predominant. This is also the first study to show such frequent changes in position before and after teaching, something that may be attributable to a combination of sample characteristics and the increased sensitivity of the research tool employed compared with earlier work.

The idea underpinning Chapter 7 is that students holding different positions on the origins are likely to demonstrate different *misconceptions* about biological evolution¹. Although at the aggregate level, this is an apparently unproblematic assumption, it appears not to have been rigorously investigated in the literature, and the relationship between different categories of misconception and positions on the origins of life and biodiversity remains largely theoretical. The data collected in this study show that the distribution of some types of misconception varies more than others between those holding different positions, and that misconceptions are common in this sample, even among those selecting a position that aligns with current scientific consensus. These findings on the extent of misconceptions and the relationship with positions are new.

Overall, the work reported in this thesis suggests that individuals who have a better understanding of the evidence for evolution, and who view the relationship between science and religion in a positive way, also tend to reform his or her position of the origins towards a more scientifically sophisticated position.

This thesis also contributes to the research community on evolution education and beyond through the development of four empirical research tools. Two of these are newly developed and the other two are modified from previous literature. First, *the Science-Religion Self-Identification Inventory (SRSII)*, newly developed based on my MSc study (Yasri and Mancy, 2012), can be used to explore views on the relationship between science and religion based on the selection of one view and on responses to five-option Likert scale items. This tool is also based on a synthesised framework developed through comparing and contrasting existing taxonomies of the relationship between science and religion, and this constitutes a contribution in its own right. The second tool, modified from Smith (2010b), serves to elicit different forms of cognitive authority

¹ In this chapter, I focus on positions rather than views because these provide more direct information regarding possible interpretations of evolution.

influencing different levels of acceptance of evolution through the use of the *Acceptance of Biological Evolution Measurement (ABEM)* based on a five-option Likert scale item and a written task. Third, the *Creation-Evolution Self-Identification Inventory (CESII)*, modified from Brem et al. (2003), examines positions of the origin of life and biodiversity and changes in the positions based on a selection of one preferred position. The tool can also examine student reasons for changing in position based on a five-option Likert scale item. Finally, the *Measure for Understanding of Science and Evolution (MUSE)*, newly developed, can be used to test student understanding of evolutionary conceptions and the nature of science. This is achieved by asking respondents to provide a range of statements that can be completed in a range of ways, and asking respondents to cross out those that do not apply.

These research tools have been found to be easy to complete at least among the student sample in this study. *SRSII* covers a range of views in which science and religion can be related. Its usefulness, validity and readability have been demonstrated not only among this Thai student sample, but also Pakistani and Scottish students as recently conducted by other colleagues. *ABEM* is able to elicit different levels of acceptance of as well as eliciting justifications for particular levels of acceptance. *CESII* enables researchers to investigate variations in positions regarding the origin of life and biodiversity and shows sensitivity in terms of its capacity to detect how positions have changed through time. In addition, it allows researchers to examine particular reasons which contribute to student changes in position. Finally, *MUSE* is useful to explore the understandings and misunderstandings of individual students or/and groups of students of evolutionary concepts, the nature of science and various aspects of the biological world. Its use allows researchers to identify specific concepts of evolutionary theory and the nature of science which students may find difficult to understand.

1.3 The significance of this thesis

I believe that this thesis should be valuable to a number of people, ranging from science educators and teachers, theologians and philosophers, policymakers and

school boards, to members of the public and religious believers, in addition to students themselves. Possible implications are discussed as follows.

In educational arenas, if science teachers and science educators believe that the aim of evolution education is to help students understand evolutionary theory and accept it as a scientifically valid explanation of the emergence of biodiversity of life, then this thesis suggests a possible way to reach this aim. That is through instructional approaches focusing on the understanding of the strength of evolutionary evidence, as well as discussing the relationship between science and religion. Concerning the implications of the relationship between science and religion for student learning of biological evolution, this study investigates four fundamental aspects that may influence the learning: different views for relating science and religion, justifications for accepting or not accepting biological evolution, positions of the origin of life and biodiversity, and student misconceptions of biological evolution and the nature of science in relation to selected positions of the origin of life and biodiversity. Therefore, curriculum plans and instructional designs can be improved through the findings obtained from this thesis.

Focusing on the implications for learners, some may have been influenced by declarations of particular faith groups that they always have to choose between science (i.e. includes evolution in this context), and religion (i.e. forms of more or less fundamentalist creationism). However, this study provides a range of views concerning the relationship between science and religion, as well as positions of the origin of life and biodiversity which concern the relationship between biological evolution and biblical creation, for students to consider in different dimensions including compatible views of the relationship between science and religion and reconciliatory positions of the origin of life and biodiversity. In addition, students can learn from this study that many of the student participants in this study, who perhaps are in the same age and religious domination, could see no contradiction between science and religion and compatibly integrate religious beliefs concerning divine creation and scientific knowledge of evolutionary theory in their worldview. Therefore, it is possible

for them too to manage perceived conflicts between science and religion, if they believe that these exist.

From a philosophical perspective, although taxonomies of the relationship between religious and scientific perspectives have been developed by a number of scholars, including Polkinghorne (1986), Barbour (1990), Haught (1995), Nord (1999) and Alexander (2007), their similarities and differences have not previously been explored in any depth. In addition, empirical support for these taxonomies has previously been lacking. To some degree, this study validates the philosophical viewpoints by integrating them with empirically collected views of the relationship perceived by a large number of students and develops a single framework of the taxonomy of views for relating science and religion.

For researchers interested in evolution education, the four research tools: *ABEM*, *CESII*, *SRSII* and *MUSE*, are available. These tools can be reused or perhaps further developed if necessary. In addition, a Thai translation is also available for each of the tools upon request. Moreover, this study first provides findings of student views of the relationship between science and religion and positions of the origin of life and biodiversity based on a Christian setting in a Buddhist society. This heterogeneous context contributes to existing knowledge of the topics which have been mainly studied in Western contexts.

Also, some recommendations can be made for educational policy makers. For example, national science curricula (based on the context of this study) and state science curricula (in other cases where educational systems are decentralised) should emphasise that evolutionary biology is a unifying concept in biological sciences and links between evolutionary biology and other biological theories have to be made explicitly by integrating evolutionary theory with other biological topics such as physiology, taxonomy, anatomy, genetics and molecular biology. In addition, policy makers may choose to create policies that science teachers and religious education teachers should introduce different ways in which science and religion can be related to their students, by focusing on the nature of science as well as the nature of religion. However, it is important to note in the policies that the teachers should not be judgemental

about personal beliefs and worldviews held by students. Apart from this, policies could be made for school boards to provide support to biology teachers as they develop their curriculum on evolution education which have to be up-to-date because research on evolutionary theory in the scientific communities is progressing rapidly.

Last but not least, applying findings from this thesis to the public domain, and in particular among those holding monotheistic beliefs, it is confirmed that science and religion as well as evolutionary theory and divine creation are not always perceived contradicting each other. Whether this is the case depends on a particular stance of the relationship between the two. There is a range of ways in which monotheistic believers can consider the relationship, and if so desired, views that can be adopted that move beyond the conflict zone to the realm of compatibility.

Chapter 2

Worldviews in Evolution Education

This chapter provides a review of existing literature on evolution education consisting of three main sections: the introduction to evolution education, explanations to the question on the origins based on religious and scientific perspectives, and the roles of worldviews in student understandings of biological evolution. These sections (2.1-2.3) are published as a conference paper in the European Conference on Education (ECE 2013), organised by the International Academic Forum (IAFOR) However, in addition to these sections, there is another section (2.4) which is not included in the conference paper. It identifies research gaps missing in the existing literature and the overarching research question of this thesis.

2.1 Introduction to evolution education

The theory of evolution is considered to be a unifying theme in biology, as exemplified in Dobzhansky (1973, p. 125)'s famous claim that "nothing in biology makes sense except in the light of evolution". Nonetheless, although evolutionary theory finds its roots in the biological sciences, its development has relied on the combined effort of professionals in other scientific disciplines ranging from chemistry and medicine to physics and geology, often engaged in observing, data collection and experimentation to enrich and validate the theory (Stearns and Hoekstra, 2005). The study of evolution is becoming ever more interdisciplinary as evolutionary models and frameworks are adopted by those working in domains as diverse as the social sciences and computer sciences. In addition, evolution also stimulates scientific development at the nexus of professionals in different fields. For example, Nadelson (2009) refers to the new field of evolutionary educational psychology which claims that our evolutionary history is an important factor to take into account in explaining

aspects of cognition and learning. In addition, it is also central to research in a broad range of discipline areas such as evolutionary psychology, evolutionary anthropology, evolutionary medicine, evolutionary computation and evolutionary economics (Stearns and Hoekstra, 2005).

In educational contexts, the teaching of evolution usually forms an important part of the biology syllabus. Schilders et al. (2009, p. 115) consider evolutionary theory as one of the major scientific concepts that underpins biological thinking which “should be one of the leading threads running through the biology curriculum”. Using as a starting point Driver et al. (1996)’s framework for conceptualizing the reasons for teaching nature of science, Smith (2010b) outlines a number of reasons for the importance of teaching evolution covering economic grounds (the need to train future scientists capable of contributing to technological advancement), utilitarian grounds (the need to help people understand scientific concepts which are directly related to their daily life), democratic grounds (the need to educate individuals in scientific reasoning skills required to make decisions about socio-technical issues), cultural grounds (the need to support individuals in appreciating the contributions of science to daily life and culture) as well as moral grounds (the need to make people aware of issues relating to the use of science in ways that are consistent with ethical and moral norms).

Among the educational literature, that relating to evolution forms a particularly noteworthy area of science education. Although some work on the topic is much older, evolution education was highlighted in 1994 in a special issue entitled “The teaching and learning of biological evolution” in the *Journal of Research in Science Teaching*. Since then, there has been a consistent increase in the number of research articles in this area published in journals such as *Science Education*, *Science and Education*, *International Journal of Science Education*, and *Journal of Biological Education*, among others. More recently, a new peer-reviewed journal *Evolution: Education and Outreach* was launched in 2008, specifically addressing the teaching and application of evolution. Later in 2009, *Science and Education* launched a special issue on Darwinism and evolution education in recognition of the double anniversary of 200 years since the birth

of Charles Darwin (12 February 1809) and 150 years since the first publication of his well-known book *On the Origin of Species by Means of Natural Selection* (24 November 1859). The increasing interest in evolution education has also been growing in recent years; for example, 13 out of 18 articles published by *Science and Education* (volume 22, issue 2) released in February 2013 directly relate to evolution and Darwinism, even though this issue is not intended to particularly address evolution education.

I believe that the development of this research area is not a coincidence. It seems likely that there are at least two fundamental reasons that contribute to the growth of research in evolution education. First, as discussed above, research on evolution has shown its inherent interdisciplinary importance as both a subject of study in its own right and as a methodological tool. Second, evolution has been the subject of considerable debate in the social sphere, largely fuelled by its relationship with religious perspectives (Smith, 2010a), thus attracting interest from educators and those interested in social studies. Specifically, one view of the relationship between science and religion is that the two are in conflict (Allgaier and Holliman, 2006). This view is evident in numerous studies based in different regions across the world where different religious traditions are predominant, including the US (Brem et al., 2003, McKeachie et al., 2002), the UK (Billingsley et al., 2012, Francis and Greer, 2001, Fulljames et al., 1991, Taber et al., 2011), the Middle East (Asghar et al., 2010, Dagher and BouJaoude, 2005, Özyay Köse, 2010, Dagher and BouJaoude, 1997), as well as the Far East (Clores and Limjap, 2006, Yasri and Mancy, 2012, Pongsophon, 2006). In the following sections I introduce a specific issue that appears to form the starting point of much of this controversy.

2.2 The origin of the issue of the origins

Leakey (1996) claims that there may be no other scientific explanations that are as controversial as biological evolution. More explicitly, Sinclair et al. (1997) argue that the origin of life and human evolution are the most problematic areas of the biological sciences. This may be due to the fact that not only does biological evolution offer answers to key questions on the origins, so too does

religion. In addition, answers to questions relating to the origins probably contribute to the philosophical issue of the meaning of life, a concern that is important for many people as it relates to their identity as human beings and the purpose of their existence. Although the precise nature of the questions addressed by biology and religion perhaps differs, the two explanations have long been claimed to be in rivalry. I argue here that a key aspect that appears to be the starting point from which many people perceive an incompatibility between science and religion is the question of the origins (Smith, 2010a). In the following subsections, two different schools of thought providing explanations for the question of the origins are discussed.

2.2.1 Religious explanations: creation narratives

In this section, I focus on Judeo-Christian religions and Christianity in particular. I refer to biblical literalists of the Genesis accounts as creationists although I acknowledge that other interpretations of this term exist.

According to Genesis 1:1 “in the beginning God created the heavens and the earth”, also creating all living things in a process lasting six days. Interpreting Genesis literally, the first life was created on the third day in the form of plants. Additional forms of life (fish and birds) were created on the fifth day, and livestock and “wild animals” on the sixth day. The final act of creation was that of mankind on the sixth day: verse 27 reads “God created mankind in his own image, in the image of God he created them; male and female he created them”, allowing them to rule over the other life that he had created (verses 26 and 31). Although the creation story spans six days, Scott (2005) points out that the word “day” used in the chapter is interpreted differently among creationists as representing a period ranging from a literal 24-hour day, through 1000 years (see Psalm 90:4, 2 Peter 3:8) to a period of time (geographical era).

It is important to note that the creation of mankind is understood by the creationists as the climax of God’s creation (Krell, 2005), as exemplified in the language used to describe this act of creation. First, it was the last creative work, and God said that it was “very good” (verse 31), whereas the others were “good” (verses 10, 18 and 25). Second, unlike the rest of the creations, it was

not only a simple act of divine spoken word but the “meeting” of plural divine subjects according verse 26 which reads “Let *us* make mankind in *our* image”. The objective pronoun *us* and the possessive pronoun *our* indicate that God was speaking to another Person, who is usually believed to be Jesus through reference to John 1:1-2. In addition, verse 27 reads that “God created mankind in his own image” which indicates the special nature of human beings in the sight of God. Furthermore, God allowed them to rule over the things that He had created according to verses 26 and 31.

Taken at face value, the explanations literally drawn from the book of Genesis seem to imply both the origin of life and the process of the origin of different forms of life, claiming that human beings and other animals were directly created in their current forms (thus implying no evolution) by an all-powerful being. Of course, this appears to contradict the modern scientific explanations to be discussed shortly. However, I reiterate here that the scriptural chapters can be understood according to a variety of interpretations, ranging from the literal, to interpretations of the biblical creation story as a metaphor, and these have different implications for the relationship with scientific explanations (Alexander, 2009, Scott, 2005).

2.2.2 Scientific explanations: abiogenesis and evolution

Many readers and school students tend to conflate explanations of the origin of life and emergence of the variety of life forms (Rice et al., 2010). In other words, when considering the term evolution, many view it holistically as the biological history of life, starting from the origin of the first molecules of life and the first living cell, the development of multicellular organisms, to the emergence of higher taxonomical animals and human beings. In fact, scientific explanations differentiate between the processes by which life arose from non-living matter and those by which life developed into the diverse forms recognised today: the former processes are those of abiogenesis; the latter are explained by evolutionary theory. “In the strictest sense, Darwinian evolution is an explanation of the origin of species from ancestral species, not the origin of the first living thing - an issue confused all too often by scientists and evolution opponents alike” (Smith, 2010b, p. 542)

To begin with the explanation of the origin of life, a range of theories of abiogenesis have been proposed (Palmer, 2013), and there is currently little consensus surrounding which of these represents the most plausible explanation (Sheldon, 2005). It is also unclear how abiogenesis and evolution interact, with some authors claiming that RNA, possibly capable of evolution, may have preceded life, and others claiming that evolution began only after abiogenesis. Nonetheless, abiogenesis explains that natural chemical reactions in the early earth formed biochemical compounds, including amino acids and nucleic acids (the building blocks of life) as demonstrated in the Miller-Urey experiment, an experiment that simulated hypothetical conditions thought to exist on early Earth, and tested for the occurrence of chemical origins of life (McCollom, 2013). Amino acids, mediated by the nucleic acids, became organised into proteins which later became known as a fundamental component of all living things. After the formation of these organic molecules, the first life arose, followed by the accumulated processes of change from simple molecules to the diversity of complex organisms over periods of time, through the processes of evolution (McCollom, 2013).

Turning to the theory of evolution, in the biological context the term evolution is generally associated with Darwinian theory (Scott, 2005, Stearns and Hoekstra, 2005) and more recent developments of this theory. Therefore, many authors use the terms *theory of evolution* and *Darwinian evolution* interchangeably. Wiles (2010, p. 18) defines the theory of evolution as the explanation of “the diversity of life on Earth [which] has arisen via descent with modification from a common ancestry”. It explains changes in species of living organisms over time as due to variation amongst individuals and processes of natural selection that lead to higher survival and reproductive rates of those best adapted to their environment, tending to increase the frequency of adaptive traits in the population (this process is often called “the survival of the fittest”, in which fitness is a relative measure of the extent to which a species is successful at survival and reproduction in a given environment). While variation is usually considered to arise randomly, natural selection provides direction to the process and takes the form of environmental pressures that differentially impact on individuals, including availability of food, changes of climate, and other forms

of competition between organisms living in the same territory (Stearns and Hoekstra, 2005). The isolation of subpopulations, through geography or genetic bottlenecks, can lead them to take different evolutionary paths, and induces speciation. Further, then, evolutionary theory purports that the current diversity of living organisms alive today originated from a small number of early ancestors (Charlesworth and Charlesworth, 2003). Being distinguishable from abiogenesis, the theory of evolution therefore explains the processes of change associated with all life including the emergence of modern humans and how we have evolved from our common ancestors with other apes (Stearns and Hoekstra, 2005).

2.2.3 Possible contradictions between the two sets of explanations

Taking the two sets of explanations into consideration, this section highlights four possible aspects of evolution that can be perceived as leading to contradictions between science and religion concerning the question of the origins. First, evolution asserts that living organisms are subject to change and development. Thus, certain species existing today might not have existed at a particular time in the past but rather came into being through evolutionary processes. Many species existing in the past no longer exist, as shown by the fossil record. In other words, currently existing species are descended from previously existing species, some of which are now extinct. This concept of evolutionary theory challenges the fundamental view associated with some creationist interpretations which rely on the “fixity of species” (McGrath, 2010, p. 187), meaning that all species have remained unchanged throughout the history of the natural events.

Second, the notion of “the survival of the fittest” according to evolutionary theory suggests that evolutionary processes had taken through “a massive struggle for existence” (McGrath, 2010, p. 188), meaning that a large number of species have died out through competition for existence within certain environmental conditions. As perceived by some creationists, this sense of “wastage” challenges the characteristics of the loving and caring God who, on seeing his own creation, believed it to be good.

Thirdly, Darwin's account of natural selection implies that evolutionary processes take place through a series of random and accidental events. This notion of randomness challenges the idea of God who intelligently designed the world. In other words, the implication of random processes is that the "guiding hand of God" is lost. A large group of evolution rejecters also argue that the successful development of modern species through genetic mutations - which on average tend to be deleterious rather than beneficial - is highly improbable (Alters and Nelson, 2002), although this argument often fails to take account of the incremental nature of evolution and natural selection. In addition, evolution rejecters often invoke the second law of thermodynamics which states that in a closed system there is a tendency towards disorder (i.e. the entropy of a system naturally increases) (Alexander, 2009). However, this law does not apply to evolutionary systems, as these are not energetically closed systems.

Finally, according to evolutionary theory, humans emerged through evolutionary processes. In other words, there is no exemption for humanity in evolutionary events: human beings were descended from other life forms. As argued by Krell (2005), this claim stands in stark contrast to the special creation of humanity as argued by Krell (2005) in which human nature is believed to be distinct and superior to others. Indeed, McGrath (2010) thinks that this might be the most difficult challenge in relation to the central issue of evolution and religious beliefs of creation.

2.3 Worldviews and evolution education

McGrath (2010) notes that the apparent contradictions discussed above have been considered in the public sphere since the early nineteenth century. These considerations persist today, including in the educational arena among school students (Asghar et al., 2010, Taber et al., 2011, Yasri and Mancy, 2012) and even biology undergraduates (Brem et al., 2003, Dagher and BouJaoude, 1997, Downie and Barron, 2000). Of course, almost all scientists, science educators and biology teachers agree that it is important for them to teach evolution and for students to gain a sound understanding of the theory of evolution as it is one of the few key concepts that underlie biological thinking (Schilders et al., 2009,

p. 115). However, unlike other scientific explanations such as cell theory, atomic theory or quantum theory, teaching and learning about evolution can never be simple, but rather remains problematic (Anderson, 2007, Eve et al., 2010)

As a science educator, I believe that the issue of perceived incompatibility between evolution and religious beliefs needs to be taken into account in teaching about evolution. In this chapter, I therefore aim to encourage science educators to be aware of the potential for non-scientific perspectives to play a role in science classrooms. However, I have no intention to imply that religious beliefs concerning divine creation should be ignored by science teachers simply because they are not scientific. Instead, I suggest that they should be considered rather carefully as student worldviews. Cobern (1989, p. 3) defines worldviews as “the culturally-dependent, generally subconscious, fundamental organization of the mind”. He notes that this organization manifests itself as “a set of presuppositions or assumptions, which predispose one to feel, think, and act” in predictable and patterned ways. Examples of worldviews might be religious or scientistic worldviews, either of which might constitute a lens through which the world is seen and interpreted. My stance is that the role of science educators and teachers is not to change students’ worldviews (or religious beliefs), but to open up ways for them to understand how science works (i.e. the nature of science) so that they are able to justify by themselves which worldviews are consistent with scientific ways of thinking. It is the responsibility of the individuals themselves to consider these ideas, possibly leading to the transformation of their personal worldview.

This particular section of the chapter therefore focuses on the discussion of three different worldviews that might be of relevance to evolution education; religious, naturalistic and religio-naturalistic worldviews. First, a range of evidence points to the primary influence of the religious worldviews on the learning and teaching of evolution, particularly those of monotheistic traditions (Deniz et al., 2008, Downie and Barron, 2000, Francis and Greer, 1999, Fulljames et al., 1991, Preston and Epley, 2009, Smith, 2010a). Second, Clores and Limjap (2006) and Fulljames et al. (1991) explain that a scientistic

worldview (commonly known as scientism), in which natural science is believed to be the only authoritative source of knowledge, also plays an important role in student learning of evolution. Third, Schilders et al. (2009) assert that there are other sets of worldviews lying in between these two radical worldviews that combine purely religious and scientific approaches and also influence student perception of evolution. These three worldviews are now discussed in greater detail.

2.3.1 Religious worldviews

In recent years, a number of research studies have been conducted to investigate the influence of religious worldviews on understandings of the theory of evolution. These studies have demonstrated that evolutionary theory is fairly frequently understood as contradictory to religious worldviews, often leading to rejection of evolution. For example, over a period of 12 years, Downie and Barron (2000) surveyed how students attending a Scottish university viewed evolutionary theory. Although there were a small number of those who rejected evolution, the researchers found that the majority of these students were religious (86% on average across the different years) and their rejection was for religious reasons. The two main religious traditions that were associated with the rejection of evolution in this study were Islam and Christianity. More generally, Smith (2010a) argues based on his review of other empirical studies that religious worldviews, especially Christian fundamentalism, are negatively related to acceptance of evolution. Indeed, Mazur (2004) shows that monotheistic beliefs are also the strongest predictor of rejection of evolutionary theory among the US public.

Other religious worldviews that are not based on monotheistic beliefs, such as Eastern religious traditions, may also influence understandings of biological evolution. For example, a large scale survey of 35,000 US adults conducted between May and August 2008 by the Pew Forum on Religion and Public Life (2008) shows that 62% of the Buddhists in the sample believed in nirvana, the liberation of the soul from the effects of karma and from bodily existence in which a person is ultimately free from suffering, desires or senses of self. About the same proportion of the Hindu sample (61%) believed in reincarnation,

according to which human beings are reborn into the world again and again either in a human form or other creatures depending on karma of the previous life. Although the existing literature is insufficient to know whether individuals holding these religious worldviews accept biological evolution, these worldviews may impact their understanding of evolution in some way perhaps in relation to the role of reincarnation in evolutionary processes.

Turning to the influence of religious worldviews on student learning of evolution, I now focus on those associated with monotheistic religious traditions. Woods and Scharmann (2001)'s study showed that students in their sample perceived religious worldviews as the main cause of conflict when learning about evolution. Similarly, Yasri and Mancy (2012) showed that learning about evolution caused considerable emotional conflict and tension for some students who held monotheistic worldviews. More specifically, about half of their interviewees were found to rely solely on religious beliefs, specifically in the form of a literal interpretation of the Bible, when dealing with contents of evolutionary theory. Although they could learn and pass the subject successfully, they either had no deep engagement with it or attempted to find evidence against evolution by focusing on its limitations. University students participating in Clores and Limjap (2006, p. 72)'s interview study provided similar responses. For example, while one participant affirmed that his religious worldviews "were capable of giving secured answer [sic] rather than evolution theory which is doubtful", another two stated that they believed in creationism "because only God knows what will happen in the future and why things are happening in this world." (p. 73).

Moreover, based on the evidence collected from learners in their respective studies, various authors describe the process of learning about evolution for many of those holding religious worldviews in strong terms as eliciting "real, deep and emotionally painful" (Meadows et al., 2000, p. 104), "emotional loss" or "existential anxiety or even crisis" (Evans, 2008, p. 263). Students who experience this kind of tension are usually presumed to learn about evolution solely for the purpose of passing tests and examinations (Dagher and BouJaoude, 1997, Dagher and BouJaoude, 2005, Woods and Scharmann, 2001, Yasri and Mancy, 2012). In sum, a religious worldview that necessarily implicates some

form of supernatural that directs creation or the cycle of life is often perceived as incompatible with the naturalistic basis of evolutionary biology. The evidence therefore points to the importance for science educators and biology teachers of better understanding the roles of religious worldviews on student learning about evolution in order to support students to learn more effectively as also suggested by Reiss (2008) and Reiss (2009b) as well as to promote a classroom environment where religious students could learn evolution more comfortably.

2.3.2 Naturalistic worldviews

Of course, not all students have been raised to be, or choose by themselves to be, religious. However, this does not mean that they do not possess a worldview. In fact, Cobern (1997) points out that how individuals understand something is rooted in their worldview. So, when students rely on science to make sense of natural events around them, they are adopting a worldview which many scholars believe that it is associated with naturalism (Scott, 2005, Matthews, 2009). Scott (2005) explains that there are two different versions of the philosophy of naturalism. One is *methodological naturalism* which Scott considers to be the fundamental stance of the modern sciences. It is this perspective that is employed when people adopt scientific methods to explain natural phenomena by natural causes. It therefore assumes natural causes; should non-natural causes or phenomena exist, these are outside the scope of what can be explained by science. It is therefore “a limited way of knowing, with limited goals and a limited set of tools”, such that if supernatural phenomena do exist, science is insufficient to understand the whole of reality (Scott, 2005, p. 67). If methodological naturalism is the sole lens one uses to interpret the world, the associated worldview is a naturalistic one. However, I note that subscribing to methodological naturalism does not preclude holding a belief set that includes supernatural phenomena, so methodological naturalism may be combined with religious beliefs in religio-naturalistic worldviews, as discussed in the next section. The other perspective is *philosophical naturalism* which differs from the former because it assumes that no non-natural phenomena exist and thus that all phenomena are subject to investigation by science (subject to the usual constraints of scientific practice). The worldview of those who subscribe to this view is therefore naturalistic.

Turning back to the influences of the naturalistic worldviews on evolution education, a number of student participants in a number of studies (e.g. Clores and Limjap, 2006, Taber et al., 2011, Yasri and Mancy, 2012) adopted naturalistic worldviews in their learning of evolutionary theory. Adopting methodological naturalism, two students in Yasri and Mancy (2012)'s study fully accepted evolution as a scientifically valid explanation of the emergence of biological diversity. When learning evolution, these students separated science from religion based on their different focuses (questions) of the reality and different approaches to gain understanding about the world. To them, learning about evolution was limited to scientific questions and methods. They did not reject the importance of religious worldviews; however, they perceived that they are beyond the scope of science. Similarly, another two students in Clores and Limjap (2006)'s interview study adopted this naturalistic worldview focusing on the nature of science when learning about evolutionary theory. They solely perceived evolution as evidence-based explanations and make no reference to religious worldviews.

Unlike these students, adopting philosophical naturalism, Priscilla, a student participant in Clores and Limjap (2006)'s study, seems to extend the realm of science to judge that religious worldviews, alongside myths and superstitions including beliefs in God and divine creation, do not meet the criteria of scientific explanations as they are solely based on human explanations rather than experimental and observational evidence about the nature. Along these lines, students in Taber et al. (2011, p. 16)'s study considered that religious claims and scientific explanations of the origins are genuinely in contrast and thus they had to choose one over the other and selected a scientific perspective. More specifically, while Ben was concerned that natural phenomena need to be explained on the basis of natural causation (elements of methodological naturalism), he further claimed that religious worldviews are doubtful because there is no proof to show that miracles exist, referring to this as "it's quite unbelievable" and "a bit funny" (elements of philosophical naturalism). Dean, who considered that the reality has to be scientifically explainable argued that religious worldviews such as divine creation or God-inspired religious texts (e.g. the Bible) "are just a sort of idea that not very imaginative people sort of think"

and that he did not believe in miracles because a miracle “defies the laws of nature”. In sum, therefore, those adopting a naturalistic worldview treat claims of the involvement of supernatural powers in relation to creation as either “wrong” in the case of philosophical naturalism, or must be interpreted in a way that fits with scientific findings in the case of methodological naturalism.

2.3.3 Religio-naturalistic worldviews

In the examples above, the students seem to apply either religious or naturalistic worldviews when dealing with evolution education, generally preferring one over the other (religious worldviews or philosophical naturalism) or setting them apart (methodological naturalism). However, in many other cases, the two worldviews are found to be mutually influential, leading to compatibility between them, and thus biological evolution is can be accepted and integrated into religious worldviews. For example, a number of scholars including scientists, theologians and philosophers, manage to reconcile their religious worldviews with acceptance of evolution and their professional role, including Alexander (2009), Collins (2006), Lennox (2007) and Tracy (2008), for example, claiming that evolution is the tool that God uses to generate the diversity of life forms.

In educational settings, two students in Yasri and Mancy (2012)’s study were able to reconcile the relationship between religious and naturalistic worldviews in different ways. Specifically, while Pavee adopted a worldview in which scientific discoveries can be fully integrated into his religious worldview as the handiwork of divine, Apai believed that the religious worldview itself is limited and thus has to be refined by scientific understanding. In addition, for Apai, the more he understood about the mechanisms of the natural world, the more he was amazed by the “intelligence of the Creator”.

Three students in Taber et al. (2011)’s study took an approach which is similar. Alisha did not form a strong position for relating the two worldviews. However, she was keen to utilise knowledge from a naturalistic worldview to solidify her religious one as she suggested that religious faith is “a big part of everyone’s lives, and so discovering your actual faith by going through it with science and

the actual reasons would be a big help to everyone” (p. 10). Anita was open to any possibility in which religious and naturalistic worldviews could be reconciled. She referred to one possible way to do so and that is similar to Pavee’s approach. She said “when you think about it deeper like with the big bang, we don’t know why it happened, it could have been God creating the universe with the big bang ... we can’t deny that the big bang probably did happen, but we still don’t know what like made it happen” (p. 11). Similar to Anita, Dominic expressed that “I wouldn’t say evolution necessarily contradicts [creation accounts] because it could be God [who] created animals and they just evolved into us or something like that” (p. 12). He also pointed out that “I like to think that science might be proving religion in a way or religion might help scientists”. In sum, apart from those holding either a religious or a naturalistic worldview, there are those who integrate both science and religion into their religio-naturalistic worldviews; in this case, evolution can be accepted alongside a belief in God.

2.4 Research gaps and an overarching research question

According to the review of the literature, learning about evolution is a complex phenomenon, influenced differently by different worldviews ranging from primarily religious, through religio-naturalistic and methodological naturalistic to philosophically naturalistic worldviews. Some of these, at least in some forms, may enhance student learning of evolution, but others may hinder it. The examples above demonstrate that, perhaps even more than other areas in education, evolution education is not simply the matter of content presentation by teachers or knowledge acquirement by students, but a matter of conceptual reformulation for individuals “to see the world in new and different ways” (Sinatra et al., 2008, p. 189). I therefore conclude here that in order to improve instructional approaches for teaching biological evolution, science teachers and educators need to take an active interest in worldviews in evolution education. And now I will change the focus of the present chapter to specific aspects of worldviews that I believe to influence on student learning of evolution.

My previous study, based on in-depth interviews with nine high school students, showed that one of the aspects of worldviews associated with student learning of evolution is student views of the relationship between science and religion (Yasri and Mancy, 2012). In this work, we identified a taxonomy of five distinct views concerning the relationship between science and religion: *science trumps religion*, *religious trumps science*, *compartment*, *contrast*, *coalescence and complementary*. In addition, we proposed that each of the views was associated with a characteristic pattern of learning about evolution, helping to explain how students seek out and engage with different sources of information about biological evolution (e.g. with the explicit goal of looking for problems with evolutionary explanations or with the goal of attempting to understand evolution as presented), leading to different patterns of conceptions about evolutionary theory.

Recognising the limitations of the small sample size in this earlier work, the present study explores in more depth four areas that arose as worthy of further investigation in order to form a more solid body of knowledge about the implications of views concerning the relationship between science and religion for student learning of biological evolution. A summary of these four gaps initiated by the study is shown below in Figure 2.1, and detailed discussions are as follows.

The first aspect is concerned with the validity and generalisability of the taxonomy of *views* concerning the relationship between science and religion identified in Yasri and Mancy (2012). The need for validity is seen firstly in the need for a more thorough examination of the extent to which the taxonomy corresponds to others existing in the literature. This is achieved in the current work through the comparison and synthesis of the identified taxonomy in conjunction with other taxonomies of the relationship between science and religion proposed in philosophical literature such as Polkinghorne (1986), Barbour, (1990), Haught (1995), Nord (1999) and Alexander (2007) and empirical studies such as Shipman et al. (2002), Hokayem and BouJaoude (2008), and Taber et al. (2011). In addition to constituting a test of the validity, the comparison and synthesis of the taxonomies proposed by the different authors

also contributes to the development of a single, synthesised taxonomy of views concerning the relationship between science and religion which is absent in the existing literature. The second need, that of generalisability, arises from the fact that the views of the relationship proposed in my earlier work were based primarily on a single study of nine high school students in Thailand studying at Christian schools; therefore, extending to a larger sample of students in broader contexts is required in order to justify whether the proposed views represent a possible range of student understandings of the relationship between science and religion. Therefore, Chapter 4 is developed to address these issues in particular.

The second aspect is concerned with the student *justifications* through science and religion for different levels of acceptance of biological evolution perceived by students. Although in my previous study (Yasri & Mancy, 2012), I do not emphasise on factors influencing student acceptance or rejection of evolution, my findings implicitly reveal that students relied on science, religion or a combination of the two when reasoning about the acceptability of evolution. For example, those who rejected evolution explained that they relied on advice from other religious believers (i.e. Nicha and Thida), religious books supporting faith (i.e. Nicha), books providing arguments against evolution (i.e. Pavee), and the Bible (i.e. Prakhun). Those accepting evolution said that they relied on their understanding of the nature of science in terms of the specific scope of scientific questions (i.e. Duangjai) and methods to investigate and construct scientific knowledge (i.e. Mothana), and that they separated science from religion. In addition, Sadudee and Apai integrated both science (as providing evidence and explanations) and religion (as providing “ultimate truth”) as their sources of information for accepting evolution as a divine-led process. Furthermore, Praporn was unable to decide whether she could accept or reject evolution, and that she thought a science teacher who is also a Christian would help her make a decision on this matter more effectively.

More broadly in the literature, although it is often suggested that understandings of both science and religion are related to evolutionary acceptance, the detail of how this relationship functions is largely unexplored,

except in small samples. A range of empirical studies have been carried out to explore student acceptance of evolution (e.g. Donnelly et al., 2009; Downie and Barron, 2000; Southcott and Downie, 2012; Özay Köse, 2010; Francis and Greer, 1999; Hokayem and BouJaoude, 2008; Clores and Limjap, 2006). These studies have tended to use only a small number of categories of acceptance, and therefore may have failed to capture subtle differences between individuals who accept some aspects of evolution but not others.

Other studies have provided data on reasons for accepting or rejecting evolution (e.g. Clores and Limjap, 2006; Downie and Barron, 2000; Francis et al., 1990; Francis and Greer, 1999; Fulljames et al., 1991; Yasri and Mancy, 2012). However, these studies are limited in a number of ways. First, those employing large samples such as Donnelly et al. (2009), Downie and Barron (2000), Southcott and Downie (2012) and Özay Köse (2010) provide reasons for accepting or rejecting of evolution based on pre-defined categories of reasons using questionnaires. Although findings based on this kind of study may be generalisable, the nature of pre-defined reasons might not reflect the real world and thus its validity is questionable. Second, studies adopting a qualitative research paradigm such as Hokayem and BouJaoude (2008), and Clores and Limjap (2006), on the one hand, provide rich information about reasons actually perceived by students themselves, on the other hand, their findings are limited to the context of such particular studies. Third, reasons for accepting or rejecting evolution are simply presented by those studies as factors influencing student opinions; however, no specific theoretical framework is used to explain what constitutes a sufficiently compelling reason for students to believe and/or accept evolution, or to use it as a justification.

If we accept understandings of both science and religion as important factors influencing student acceptance of evolution, it becomes important to understand these in much more detail. In this work, I consider student levels of acceptance of evolution and how they justify their level of acceptance through their use of arguments relating to scientific and religious sources. Specifically, Chapter 5 addresses these issues in more depth.

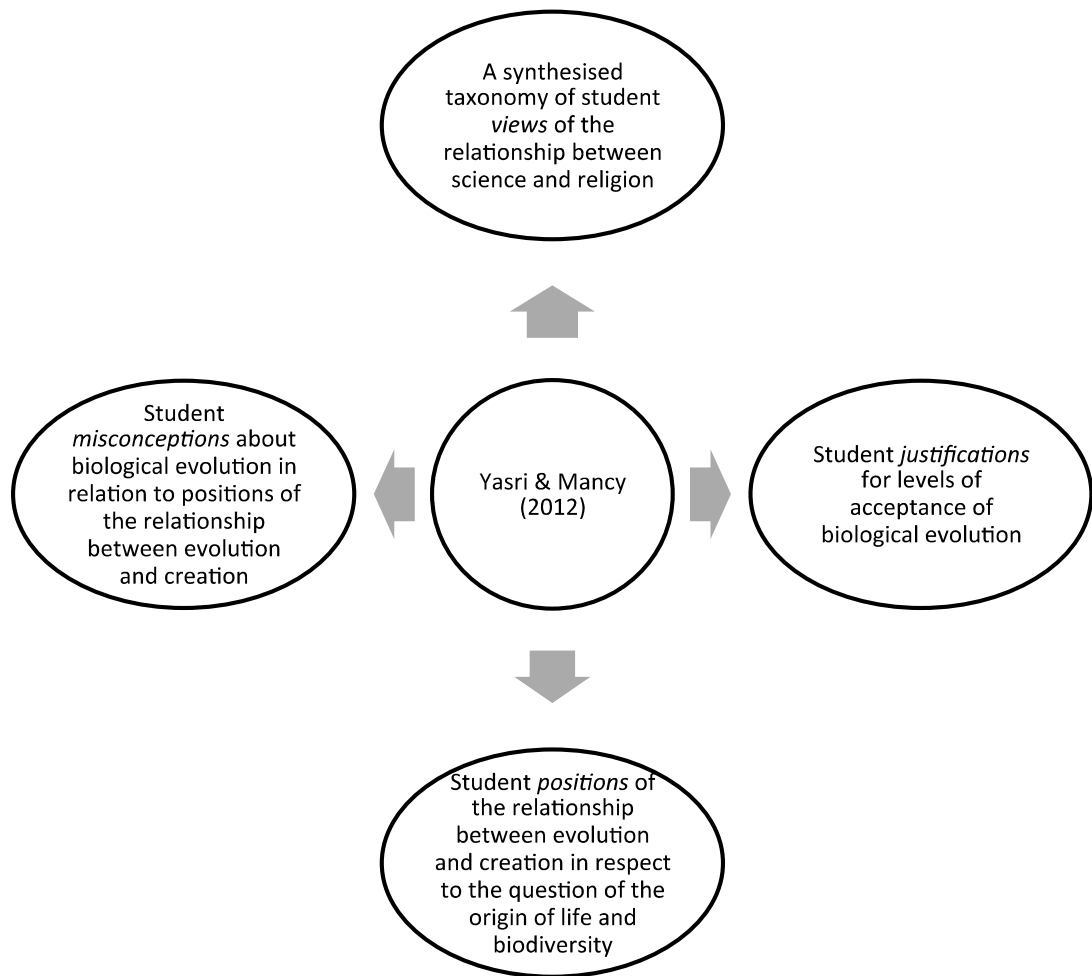


Figure 2.1 Summary of four strands of research focused in this PhD thesis

The third question is concerned with student *positions* on the relationship between biological evolution and biblical creation in respect of the question of the origin of life and biodiversity. In fact, although we explicitly focused on the views of the relationship between science and religion in the previous study (Yasri and Mancy, 2012), we also noted in that article that there is another level of the relationship specifically focusing on positions of the relationship between biological evolution and biblical creation. This PhD thesis takes this specific level of the relationship into consideration in more depth. Similar to the taxonomies of the relationship between science and religion, classifications of the relationship between biological evolution and biblical creation need to be developed into a single framework. This is due to the fact that authors have classified different positions of the relationship (Scott, 2005; Nelson (1986); Verhey (2005) and Brem et al. (2003) but these have not been synthesised to

develop to form a single framework. This thesis therefore aims to address this issue. Unlike the taxonomy of the relationship between science and religion, the classification of positions of the relationship between biological evolution and biblical creation is more empirically advanced in the existing literature. This is largely due to the contribution of Brem et al. (2003) who propose five positions of the relationship and develop a research instrument for classifying them which is successfully used among college students in the US. However, they fail to include some positions which are identified in other literature such as Scott (2005) and Verhey (2005). The role of abiogenesis in the relationship with creation (in addition to that of evolution), also remains unexplored and insufficiently unacknowledged in this work. This thesis aims to continue to work on this topic by having Brem et al. (2003)'s work as a starting point.

Not only does my earlier work draw attention to the importance of the study of the relationship between biological evolution and biblical creation in my search to understand how students learn about evolution, its findings hint at the potential for students to change their positions of the relationship between biological evolution and biblical creation in respect to the question of origin of life and biodiversity. Specifically, there are two students in Yasri and Mancy (2012)'s study who implied that they have changed their positions on the relationship. First, Nicha said that she started learning evolutionary theory in her school without this having any negative impacts on her religious beliefs when it was taught in the light of biodiversity of other living organisms. In other words, she started with a position in which evolution is accepted. However, once the topic of human evolution was introduced to her class, she began to doubt and ended up adopting a position in which evolution is rejected for religious reasons. The opposite is true in the second case. Sadudee started viewing the biological world according to the literal interpretation of biblical account of creation which is likely to be associated with a position where evolution is rejected in some way. However, at the end of the course, he thought that the scientific explanations and evidence for evolutionary theory were convincing and integrated these with his religious worldview, concluding that God might use evolution to generate the diversity of life forms by first creating small living things and letting them evolve to be more complex

organisms, until the current diversity emerged. In fact, Verhey (2005) studies something similar and student changes in position are reported in his study. However, with the limited number of positions of the relationship and the limited number of participants, a further investigation including a wider range of the positions and extending to a larger sample is required to statistically validate his findings. Chapter 6 is therefore developed in order to provide a framework of the positions on the relationship between biological evolution and biblical creation, as well as to explore how students change their positions throughout the course of study and to what reasons they attribute any change in their position. As a science educator who wishes to understand how to facilitate a teaching of evolutionary biology that makes it accessible and acceptable learners while respecting their beliefs and worldviews, answering these questions is important since understanding the extent to which positions are flexible and the causes underlying changes, because understanding acceptable reasons for change might form the basis for the development of pedagogical approaches.

The fourth question is concerned with student *misconceptions* about biological evolution and the nature of science in connection with their positions of the relationship between biological evolution and biblical creation in respect to the question of the origin of life and biodiversity. I agree with Smith (2010a) that the aim of evolution education is for students to accept evolution as a scientifically valid explanation of the emergence of the diversity of life forms. However, I also hope that they are able to achieve this through acceptance of a scientifically accurate version of evolution. In fact, in my previous work, some students who accepted evolution demonstrated some misconceptions about evolution (i.e. Lamarckian inheritance) and the nature of science (e.g. Sadudee in Yasri and Mancy's 2012 study). In addition, there has been a long debate in the literature about whether student understanding of evolutionary biology is related to their acceptance (see Smith, 2010a); however, the evidence seems somewhat inconclusive. It may be that existing measures fail to distinguish between sets of misconceptions of learners holding different positions either because they are not exhaustive or because they are generally analysed at aggregate level, and overall acceptance may not relate as strongly to

understanding as positions do to particular patterns of misconceptions. It is worth exploring which misconceptions learners are likely to experience in order for teachers to address these misconceptions appropriately. Therefore, there is a need for the development of a measure that captures all identified misconceptions (rather than just a subset) and is easy for students to respond to in order that a large number of students can be involved. In addition, there is a need to consider the relationship between student misconceptions about evolution and stated positions (this being a rather more detailed way of capturing at acceptance). Chapter 7 therefore aims to investigate all of these issues.

In summary, the overarching question that drives this PhD research is: *what are the patterns of student responses to evolution and their relationship with scientific and religious worldviews?* The patterns of student responses that form the focus of this work are concerned with *views* of the relationship between science and religion, *justifications* for accepting or rejecting evolution, *positions* on the relationship between biological evolution and biblical creation in respect to the question of the origin of life and *misconceptions* of biological evolution in relation to the positions of the origin of life and biodiversity. In order to obtain the diversity of patterns of student responses, a survey-based study using a questionnaire focusing on a religiously heterogeneous context is selected, and the study conducted in Thailand. The following chapter discusses the reasons for the particular research approach selected, and describes the methods employed. Then follow the four empirical chapters that form the main contribution to the literature. Finally, Chapter 8 summarises the findings from the four empirical chapters in order to propose an answer to the overarching question.

Chapter 3

Research Methods

This chapter describes the development of the questionnaire containing newly constructed items as well as those modified from earlier work. In addition, it describes empirical work consisting of a pilot study, the recruitment of the participating school and student participants, and data collection. However, data analysis is separately discussed in each of the empirical chapters. Finally, it describes some ethical aspects which are considered throughout the conduct of this PhD research.

3.1 Justification of the research methods

I now discuss the practical conduct of the core research on which this thesis is based. Although the four proposed studies focus on different aspects of the implications of views concerning the relationship between scientific and religious perspectives, one commonality among them is the need for a research methodology applied to a large sample in order to see patterns of student responses to the different aspects, and that is why a survey study based on a questionnaire is selected in this thesis. Apart from the need for data collected from a large group of sample in order to fulfil the gaps, there are four additional reasons for the selection of the use of questionnaire which are now discussed as follows.

First, one of my personal aims was to contribute to other researchers interested in evolution education a set of research tools that can be directly used or further developed if necessary. A survey questionnaire makes this possible as it can be reused and translated in a relatively straightforward manner. Second, I wanted to explore and validate the diversity of views of the relationship between science and religion uncovered in my earlier work, as well as perceived reasons for accepting or rejecting evolution, positions of the relationship

between biological evolution and biblical creation, and patterns of conceptions of biological evolution. It was therefore important to maximise these by focusing on a religiously heterogeneous context. Because I necessarily hold my own views on many of the issues under investigation, in order to identify differences between participants from different religious backgrounds, I wished to avoid my influence on respondents being too overt, and an approach that allowed me to interact with them in a less direct way was thus preferable. Although a questionnaire does not necessarily guarantee this, my supervisory team and others who reviewed the questionnaire hold different views and it was hoped that their individual sensitivity to their own viewpoints, would help to guard against wordings that were too leading. In addition, some of the questions may, for some students, have been relatively personal (especially in a religiously heterogeneous context), and I wished for the data collection to be conducted at an individual level, and for anonymisation to be straightforward. Therefore, a survey study based on a questionnaire seems to be the only sensible research tool that allows me to meet this need. Finally, at a very personal level, since I had learned to analyse qualitative research data in depth from my MSc dissertation, I now wanted to gain more experience in the conduct of quantitative data analysis research in order to be as well-equipped as possible to both understand and direct research using a range of methods on my return to Thailand where I will be working as a lecturer in Science Education after the completion of this PhD study.

3.2 Development of the questionnaire

A questionnaire approach has been widely used in a number of studies in the area of evolution education, in particular by those focusing on student acceptance of evolutionary theory (e.g. Downie and Barron, 2000, Ingram and Nelson, 2006, McKeachie et al., 2002, Özay Köse, 2010), student understanding of evolution and the nature of science (e.g. Lombrozo et al., 2008, Ingram and Nelson, 2006), student perceptions of the impacts of accepting evolution (e.g. Brem et al., 2003) and student positions of the relationship between evolution and creation (e.g. Brem et al., 2003, Verhey, 2005, Winslow et al., 2011). However, none of these could be used directly in order to obtain answers to the

four aspects of interest (i.e. *views* of the relationship between science and religion, perceived reasons for accepting or rejecting evolution, *positions* of the relationship between biological evolution and biblical creation in respect to the question of the origin of life and *conceptions* of biological evolution in relation to the positions of the origin of life and biodiversity), therefore a new questionnaire containing specific questions corresponding to the aspects of interest needed to be developed.

In sum, the questionnaire used in this study consists of two parts. Part One is aimed at investigating demographic information such as grades (M4, M5, M6), ages (15, 16, 17, 18) and religious orientations (Buddhist, Protestant, Roman Catholic, Muslim, Agnostic, Atheist and no religious orientation)² using a tick-box format. While grades³ and religious orientations were treated as categorical variables in data analyses, age is treated as a continuous variable. Part Two is divided into four main sections, corresponding to the four aspects of interest: *views* of the relationship between science and religion using a tool named *the Science-Religion Self-Identification Inventory* or *SRSII* (see Appendix A), student *acceptance* of biological evolution using a tool named the *Acceptance of Biological Evolution Measure* or *ABEM* (see Appendix B), *positions* of the origin of life and biodiversity using a tool named the *Creation-Evolution Self-Identification Inventory* or *CESII* (see Appendix C), and understanding of conceptions of evolutionary theory and the nature of science using a tool I have called the *Measure of Understanding of Science and Evolution* or *MUSE* (see Appendix D). Detailed discussion of the development of questionnaire items and rationales for their inclusion will be presented later in each of the empirical chapters in order to provide this information for readers at the most pertinent

² Descriptions of agnostic and atheistic are provided at the bottom of the questionnaire.

³ Grades can also be thought of as ordinal variables. However, in this analysis, the intrinsic ordering of different educational levels is not considered. In contrast, the analysis categorises levels as educational experiences concerning interactions of science and religion in school. Therefore, the experiences of individuals in the different grades are qualitatively as well as quantitatively different, and it was decided to use grade information as a categorical variable to split the sample into groups.

moment. In the following subsections, however, the overall approach for the development of the questionnaire is described.

3.2.1 Construction of the research tools in the questionnaire

In this step, a number of research articles are adopted as a starting point for developing the four research tools in the questionnaire. First, I used my own work (Yasri and Mancy, 2012) alongside philosophical literature to develop *SRSII*, which is the first relatively standardised research tool eliciting views of the relationship between science and religion as far as I am aware of. Wordings used in the questionnaire are derived from students' actual words with only minor modifications. Seven statements representing seven views for relating science and religion are included with a blank space for participants to fill in other possible views. Two tasks are required to be completed by participants. First is for participants to provide their level of agreement on each of the views based on a five-category Likert scale format. Second is to select only one statement that best describes their actual view of the relationship between science and religion. However, if none of the provided statements capture their actual view, they are able to provide a written explanation in the space given.

Second, I used Smith (2010a)'s paper as a starting point to develop *ABEM*. Smith (2010a) argues that existing research tools for examining acceptance of evolution fail to determine which particular aspect or aspects of evolution they measure. Therefore, he suggests other researchers to be explicit when measuring acceptance of evolution and he provides an example how acceptance of evolution as a scientifically valid explanation can be measured. Starting from this suggested approach, I modified Smith's question slightly in order to make it more understandable for school students. The question asks participants to select a particular level of acceptance of evolution based on a five-category Likert scale format (strongly accept, accept with reservation, unsure, reject some parts and strongly reject). In addition, a newly constructed open-ended question is added in order to ask participants to provide reasons for their selection of a particular level of acceptance. This additional question is needed for eliciting what constitutes a sufficiently compelling reason for participants to accept or reject evolution as a scientifically valid explanation.

Third, I used Brem et al.'s (2003) work as a starting point to develop *CESI*. From their list of positions, two other positions are added and one slight modification is made in conjunction with the classification of the different positions proposed by Scott (2005), Verhey (2005) and Collins (2006). Eight statements representing positions of the origin of life and evolution in relation to religious beliefs, with two columns for the students to choose their position both before and after undertaking the course and including an "other" position for them to describe any alternative position. There are also three statements asking for reasons for their changes with a blank space for them to fill in other possible reasons. While the first task requires the students to select one position, the second asks students to rank from 1 (strongly disagree) to 5 (strongly agree) depending on their levels of agreement with the reasons.

Fourth, I constructed *MUSE* as a new tool by using Smith (2010b) as a starting point. Taken from other empirical studies, Smith (2010b) presents a number of misconceptions about evolutionary theory and the nature of science. From Smith (2010b)'s list of misconceptions in conjunction with other science education literature, I constructed 12 incomplete statements about biological evolution and the nature of science. In order for participants to complete the sentences, a number of phrases (or terms) which contain both scientific misconceptions and correct conceptions are provided, and they are asked cross out any phrases (or items) provided in the questionnaire that they perceive as incorrect

3.2.2 Refinement of the questionnaire

After agreement about the formats, layouts, terms and wordings used in the questionnaire between my supervisor and I was reached through repeated discussions, I consulted other colleagues interested in science education composing a post-doctoral researcher, three PhD candidates, and two Masters students, in order to ensure that the questionnaire is suitable to elicit those aspects of interest and refine it as appropriate. In addition, this was aimed to justify the clarity of the questions, as well as the simplicity of the layouts in order to make the final version of the questionnaire fit for purpose.

These science educators were asked to play two different roles. One is for them to be critical of the questionnaire items according to their views as working researchers. The other is for them to answer the items as if they were student participants. This conduct yielded beneficial feedback. On average, it took 30 minutes to complete the questionnaire. They also suggested minor revisions on the layout and consistency of terminology used. Although at this stage, the expected research subject, high school students, were not yet involved, these researchers suggested that, in general, the level of the language and technical terms used was accessible by students ranging from high school to university students.

3.2.3 Ethical approval of the questionnaire

The conduct of the study obviously had ethical considerations since it involved data collection with human participants, at times related to relatively personal constructs. The ethical guidance provided by the University of Glasgow was considered carefully and the procedures followed according to the local protocol. Before data collection was conducted, the actual questionnaire and research protocols were presented to the Ethics Committee for Non Clinical Research Involving Human Subjects of the School of Education in order to gain approval for the ethical conduct of this research. The response from the School Ethics Committee was that the survey could be carried out. Also, a permission letter (shown in Appendix E) and Plain Language Statement of the study (shown in Appendix F) were approved by the Committee and could be used to gain official access to the participating school.

3.2.4 Translation of the questionnaire

As this study was conducted in a Thai context, I translated the questionnaire into Thai from the original version in English using a literary approach in which complete meaning, word orders and expressions were carefully translated. The accuracy of translation was revised by two Thai colleagues. One held a Master's degree in Interprofessional Science Education and Communication and the other a PhD in Biological Sciences from the University of Glasgow. Both were invited to take part in this process because they are personally interested in this

research topic and familiar with evolution education as well as the technical terms used in this subject. In addition, both are fluent in both Thai and English.

In addition, the readability of the translation was revised by two teachers of the participant schools. One is the head of the Academic department teaching general science and mathematics and the other the head of the Religious Education (RE) department and currently teaches RE courses. In fact, it was mandatory to present the research instrument to the head of the Academic department in order to gain approval to conduct the survey in this school. The two teachers consulted were willing to suggest improvements to the readability and the appropriateness of the translation in terms of scientific language used among school students, as well as religious terms.

It should be noted that neither *SRSII* nor *CESII* employs the use of multiple items to test respondents' understanding of views for relating science and religion and positions of the origin of life and biodiversity for at least two practical reasons. First, adopting such an approach would require additional time for respondents to complete the questionnaire. More specifically, *SRSII* contains 7 and *CESII* 8 items in the actual form of the questionnaire. These 15 items would require at least 5 minutes for respondents to read through and to respond accordingly. Indeed, careful respondents may take longer than that. Second, I acknowledge that excluding multiple items may provide opportunities to check respondents' understanding of particular items in some degree. However, I am concerned that writing "same" points in multiple ways may also lead to spurious contradictory responses if the corresponding statements were interpreted differently by respondents. This situation may also lead to arbitrary responses due to questionnaire fatigue. Nonetheless, the validity of the findings can be confirmed in a variety of ways such as crosschecking between responses to the Likert items and the selection of one best description, as explained in Section 4.7.

3.3 Pilot study of the questionnaire

A pilot study was conducted among 20 high school volunteers who attended the participating school. The volunteers were invited to take part in completing the Thai version of the questionnaire in which a few minor revisions suggested by the two teachers had been made (i.e. typos). A group of 10 volunteers were first invited to a seminar room, and an introduction to this research was first given by me. This was followed by distributing a questionnaire to each of them and explaining how the questionnaire could be completed as well as their right to withdraw their participation and their anonymity. Another group of 10 volunteers were later invited and the same process was repeated.

This pilot study showed that the volunteers found no difficulty in answering the questionnaire items and they could complete the questionnaire within 45 minutes on average including complete responses to written tasks. No additional concern was suggested by the volunteers and all questions were answered without additional clarification being required. This therefore ensured, as far as reasonably possible, that the questionnaire was suitable to be distributed to a larger group of students. It should be noted here that these 20 returned questionnaires were later combined with those returned by student participants.

Reliability tests of the questionnaire items based on a Cronbach's alpha analysis was not carried out in this study on purpose. This is due to the fact that the analysis is used to investigate internal consistency of questionnaire items (i.e. items measure the same aspect). In contrast, in this questionnaire, most of the variables are categorical and also assessing different constructs, representing different levels of acceptance, positions of the origins and views of the relationship. Therefore, it is not expected to see any internal consistency between the variables. Thus, the purpose of this pilot study was only to see whether the students find the questionnaire items understandable and easy to complete.

3.4 Participants

3.4.1 The participating school

I intended to maximise the number of participants who might be aware of this topic by focusing my study in Christian school settings where students should have encountered with both biblical accounts of divine creation and evolutionary theory. Four Christian schools were initially chosen as they showed support to my previous research (MSc dissertation). However, three had to be excluded for different reasons. One Baptist school decided not to include evolutionary theory in their biology curriculum for religious reasons; instead, evolution was set as an optional and self-study topic in which no formal assessment was required. According to the interview with one student in this school who took part in my MSc research project, none of the students in this school had taken this optional topic for some years. Having no balance between science and religion in the context of evolution education, I decided not to conduct my survey in this setting. Two Catholic schools (both for girls) were keen to support the previous work; however, no formal response was received from them for the present study. Therefore, this practical reason made it impossible to conduct this research in these girls' schools.

Interestingly, the only school, a private Protestant school, for which permission to conduct the survey was given, is in many ways the most interesting one. This is due to the fact that the greatest diversity of views concerning the relationship between science and religion was demonstrated by the participants from this school in my earlier study (five participants in total contributed to four out of five different views of the relationship). In addition, students are not required to hold a Christian faith in order to attend this school, and in addition to students from Christian families, there are many Buddhist students in the school too, and this perhaps contributes to the diversity of views concerning science and religion. Moreover, the religious education department of the school is known to be very active as evangelical events are run by the department each year, and the number of new Christian believers is growing each year as personally noted by the head of the department. Likewise, the science education department of the school is also known to be academically strong. For

example, there have been students from this school who have represented Thailand in International Biology Olympiads, an academic competition for secondary school students, and who have won their respective National Biology event, according to the information provided on the school's website. The active roles of the two departments should contribute to some interesting interactions between science and religion in the school which warrant investigation. The main downside of this school is that is unisex (male).

In line with other public schools, this Thai Christian school includes basic education and follows the national curriculum. In upper-secondary education (for students aged between 15 and 18 years old), the school offers a science-mathematics programme in which students undertake physics, chemistry, and biology alongside mathematics in an intensive manner. Evolution is one of the biology components at this educational level. According to the national curriculum, it covers the concepts of abiogenesis, evolutionary evidence (i.e. fossil records, comparative anatomy, comparative morphology, comparative embryology, bio-geographical distributions of animals, and molecular biology), microevolution, macroevolution, population genetics, mutation, speciation, and human evolution. In general, it takes one third of an academic semester which is approximately 15-20 hours of teaching time. In principle, although teaching materials, methods, activities, and content may be different from school to school, biology teachers have to cover all of the aspects mentioned above regardless of the school they teach in.

In this school, all students also have to attend a Bible study session at the school's church at least once a week and this is a mandatory part of the school's curriculum. One of the biblical concepts provided in the sessions is divine creation, and teaching is based on the book of Genesis. In addition, every morning, a five-minute Bible lesson is regularly taught through school audio systems before students start their study. Therefore, all high school students in the science and mathematics programme of this school are assumed be fairly familiar with both biological concepts related to evolutionary theory and biblical concepts including divine creation. In addition, the RE department occasionally organises activities relating the relationship between evolution and creation.

For example, in 2007, there was a seminar entitled “DNA: the miracle of life” given by a Christian molecular biologist. This seminar was set particularly for all high school students who enrolled in the science-mathematics programme, although it was not compulsory. My understanding, based on informal discussion with students who attended this seminar, is that the main aim of the seminar was to introduce the concept of intelligent design to the students. In June 2009, there was a seminar entitled “God and Evolution: the debate of the century” given by two speakers: an atheist biologist and a Christian medical doctor. In a debate format, these two speakers presented to students a range of arguments held by them as well as evidence supporting their arguments. Over 200 students participated in this seminar. The Christian medical doctor has actually been invited to give other evangelical talks to students in topics related to God and science in this school from time to time. In addition, I myself was invited to give a seminar on the topic of my MSc dissertation which was believed by teaching staff to help a large group of students to learn different ways for relating science and religion. This seminar was made known in the school through posters and some individual teachers including both religious education and biology teachers. However, it was not compulsory for students to attend. There were about 50 high school students and 10 teachers of the school who attended this seminar (of the whole student body of 3000). At the time of data collection in 2010, students involved in this study might have been to any of these seminars or talks, although it is unlikely that they would have attended all.

Both the curricular and extra-curricular activities provided by the school make the school itself and its students very interesting and distinctive. Although the study might be critiqued on the grounds of gender limitation, I consider that conceptual variation, which may be caused by the range of experiences gained from the diversity of school activities, is probably more enlightening, given the questions under consideration.

3.4.2 Student participants

There are three grades in an upper secondary level in Thailand. These are called M4, M5 and M6 and, in principle, are equivalent to 16, 17 and 18 years of age, respectively. However, there is slight variation of ages in each grade, depending

on student performance and time when they first entered to the school such as ages of M4 students can vary from 15 to 16 years. In principle, an admission to the upper secondary level of this school is open only for those who complete a lower secondary level from this school which starts from M1, M2 and M3 (13, 14 and 15 years of age, respectively). This information suggests that M6 students should have been exposed to school activities including those held by the RE department for at least 6 years.

The target group of student participants in this study is those attending the upper secondary level - M4, M5 and M6. There are two reasons for this selection. The first is that they have had encountered Christian activities and teaching from the school for some years and this would make the students, especially those from non-Christian backgrounds, familiar with the concept of divine creation to some degree. Another reason is that they should have had acquired some understanding of scientific explanations of life including aspects of evolutionary theory. Based on the school curriculum, M4 students undertake a biology course on cell biology and taxonomy. M5 students undertake a biology course on comparative anatomy and animal physiology. M6 students undertake a course on evolutionary theory and genetics. Since the final graders are the only group of students who directly encounter the theory of evolution, they are subject for the study on changes in positions of the origin of life and biodiversity after taking the course, and reasons for changing (Chapter 5) in which the set of questionnaire questions is slightly different from the one given to M4 and M5 students.

3.5 Data collection

Before data collection was carried out, the Head of the academics department of the participant school allowed me to meet him in order to present the purpose of the data collection, research procedure and anticipated outcomes of the study. After having permission to carry out the data collection and being informed that the research related to science and religion in general, he invited the Head of religious education (RE) department, as well as two science teachers, to take part in assisting the data collection. A discussion with them

led to an agreement to conduct the data collection on Fridays from February until March 2010 in a lecture hall. An hour on each Friday when the students were expected to attend an RE class was given for this research. However, in order to be explicit to the students that this research was neutral in relation to its position on scientific and religious viewpoints, even though it took place during the RE class, the presence of teachers from both science and RE departments was requested.

On the first Friday, M4 students from three different classes (over 150 in total) were assigned by the teachers to come to the lecture hall. After the students were seated, the research topic, questions of interest and the questionnaire were made known to them. Also, the students were clearly informed that their choice of participation was fully voluntary. However, the teachers suggested that in order for the school to avoid any possible chaos, those who did not want to participate in the research should remain seated in the hall. They were allowed to have any free-choice activities which made no disturbance to those who wanted to take part in the research.

A questionnaire was already placed on each chair before the students came in so that the decision of each student whether they participate in the survey or not was unknown to me and the teachers. For those who wanted to take part, they were asked to start filling in the questionnaire. The teachers were sitting on the back and I was in the front of the hall. By doing this, the students would feel no pressure from their teachers in regard to their voluntary choice. The pressure from me was minimised by my personal awareness (not to look at anyone in particular, unless attention is called) as well as impersonal relationship between the students and me. However, I had to remain in the front because the participants were encouraged to ask any questions that they might encounter during completing the questionnaire. At the end of the hour, they were given a word of thanks and asked to leave the hall without taking the questionnaire away from the chair. After they had left, all questionnaires were collected. The completed questionnaires were separated from those that had not been completed.

Although the first data collection went well and the number of responses (completed questionnaires) was very good ($N = 115$), the large group of students made it difficult for me to deal with questions asked by the participants. Therefore, I asked permission from the teachers to meet only one class on each Friday and the request was granted. On the second and the third Fridays, two different classes of M5 students were asked to come to the hall. There were over 50 pupils in each class and thus the research invitation was made known to over 100 of them.

The same procedure conducted among the M4 participants was applied with these M5 students. I expected to meet another M5 class in order to obtain a comparable number of students with the M4 students. However, for an unknown reason, I was informed by the teachers that it was not possible for me to meet another M5 class. Therefore, a number of responses was slightly lower among this group ($N = 87$). The same protocol of data collection was conducted on three following Fridays with three M6 classes. A slightly modified set of questionnaires was used among this sample according to the rationale stated above since these students had studied evolution in particular. Based on these three times of data collection, 105 completed questionnaires were collected. However, since there were 20 returned questionnaires from the pilot study in which all respondents were M6 students, a total number of this group of participants was 125.

All quantitative data were coded in IBM SPSS Statistics 19 and this software was also used to conduct statistical analyses. Details of the analysis are described in each of the empirical studies. Qualitative data obtained from a written task in the *Acceptance of Biological Evolution Measurement (ABEM)* was analysed by a template-analysis method.

3.6 Ethical considerations

A final topic described in this chapter is concerned with ethical considerations of the conduct of this research study. After being approved by the School Ethics Committee, the official letter and Plain Language Statement explaining the

purpose of this research, target groups of participants, the approach from data collection and anticipated outcomes together with the actual questionnaire in Thai were sent to the head of the Academic department of the school which was later passed on to the head of the RE department. After having a face-to-face discussion with both of the teachers concerning the detail of the research, the survey was allowed to be conducted as mentioned above.

All of the participants were fully informed about the study and their rights during the process of data collection. Apart from verbal explanations by the researcher, the covering letter of each questionnaire also clearly states four fundamental rights. First, their participation in this study is fully voluntary. Second, they can refuse to answer any questions as they wish. Third, they can withdraw their participation at any time for any reason. Fourth, their personal identity remains fully anonymous and confidential. Indeed, the student participants were not asked to provide their name in the questionnaire which also confirms their confidentiality and anonymity.

Chapter 4

Views of the relationship between science and religion

This chapter⁴ discusses views of the relationship between science and religion from both education and philosophical literature. It begins with a review of relevant studies on how taxonomies of views concerning the relationship between science and religion are used in educational and philosophical literature. It then compares and synthesises the taxonomies from the philosophical literature in conjunction with the educational literature, leading to the development of a new research tool, the *Science and Religion Self-Identification Inventory (SRSII)* used in the empirical work on student views of the relationship between science and religion. The usefulness, reliability and validity of the inventory are also discussed.

This chapter provides some extended explanations for the previous literature on student views of the relationship between science and religion. While some students hold one of the incompatible views (i.e. science trumps religion, religion trumps science or compartment), a larger number of the participants adopt one of the compatible views (i.e. contrast, coalescence or complementary). This therefore points out that sophisticated understanding of the relationship between science and religion can be fruitful to evolution education by giving positive starting points for students to view the theory of evolution as a friend rather than an enemy of religious beliefs.

⁴ The research that informed this chapter has also contributed to the development of Yasri et al. (2013) published in *Science & Education*. The permission to include this material in this thesis is attached in Appendix J.

4.1 Introduction

In their attempts to understand the universe, individuals are known to employ the explanations of natural phenomena offered by both science and religion (e.g. Stolberg, 2007). These explanations have often been perceived as being in conflict (Preston and Epley, 2009), but a range of opinions about the relationship exist. For example, Mahner and Bunge (1996) argue that science and religion are inherently incompatible in terms of their doctrinal, metaphysical, methodological and attitudinal perspectives. Nonetheless, there are scientists who view science and religion as compatible systems (Collins, 2006). Perceived conflict is particularly obvious for certain scientific topics, of which the classic examples are the origins of the universe and the origins of life, particularly in the context of Judeo-Christian history and practice. For these topics, scientific and religious knowledge systems offer potentially conflicting explanations and can thus be thought of as competing for “explanatory space” (Preston and Epley, 2009). In the science education literature, several studies have demonstrated that student viewpoints on the relationship between scientific and religious explanations of the origins of life can affect learning outcomes (Ingram and Nelson, 2006, McKeachie et al., 2002), learning approaches (Yasri and Mancy, 2012) and the perceived societal and personal impacts of accepting evolution (Brem et al., 2003). As a result, Reiss (2009a) argues that although the relationship between science and religion may fall outside the classic content domain of science education, it is likely to be helpful for teachers to understand more about student views of this relationship that they are likely to encounter.

Understanding perspectives on the relationship between science and religion has the potential to explain certain individual differences in science teaching and learning processes and outcomes, making these views an important topic in science education research. For example, Yasri and Mancy (2012) show that student approaches to learning about evolution can be linked to their beliefs about the relationship between science and religion, helping to explain how they seek out and engage with different sources of information about evolution with the explicit goal of looking for problems with these or of attempting to

understand. Furthermore, learner understandings of the nature of science have been linked to acceptance of evolution, and these findings may be explained through the lens of the relationship between science and religion (Lombrozo et al., 2008). It has also been suggested that explicit teaching of a range of views on the relationship between science and religion may help to strengthen learner understandings of the nature of science itself (Yasri and Mancy, 2012).

The philosophical literature describes a range of views concerning the relationship between science and religion that are generally presented in the form of taxonomies that distinguish between qualitatively different understandings. Although there is some debate regarding the extent to which individual views are well defined and distinct (Reich, 2010), these taxonomies provide a useful starting point for empirical research. There is, of course, considerable overlap between taxonomies, but there are also subtle differences, and these are likely to affect the comparability of studies that employ distinct frameworks. In order to address this problem, I synthesise the main taxonomies to form a unified framework that researchers can employ in comparing existing work and then use this to develop a standardised research tool designed to identify individual views of the relationship between science and religion. I demonstrate the value of the tool by providing findings from three student samples from culturally and religiously diverse settings (UK, Thailand, Pakistan)⁵.

This paper begins with a brief review of the use of taxonomies regarding the relationship between science and religion in the educational literature. I then present the main taxonomies found in the philosophical literature and synthesise these into a single framework. The framework is then compared with taxonomies described in empirical work. I introduce a tool based on this framework and provide data on its use to assess learner and pre-service teacher views concerning the relationship between science and religion. I discuss the potential of the tool to support a more consistent approach to assessing individual perspectives on the relationship between science and religion.

⁵ Another colleague (the second author in the paper) was responsible for the data collection in the UK and Pakistan (Yasri et al., 2013).

4.2 Taxonomies of views for relating science and religion

A broad range of views on the relationship between science and religion can be found in the philosophical literature, where they are generally presented in the form of taxonomies composed of qualitatively different views or understandings of the relationship. Such taxonomies can be useful to researchers interested in investigating links between a particular view and educational outcomes. However, it is important to understand how the taxonomies themselves relate to one another in order to be able to compare studies that use different frameworks. Indeed, this understanding would help researchers compare findings in the existing science education literature, something that is currently hindered by the selective use of taxonomies. In this literature, authors often fail to make fully explicit their justification for using a particular taxonomy, such that the inclusion of particular views can appear arbitrary, especially as many educational researchers refer to a very limited number of taxonomies. For example, Shipman et al. (2002) referred to three taxonomies (Barbour, 1990, Haught, 1995, McGrath, 2010), while in recent work, Taber et al. (2011) and Reiss (2009a) referred only to Barbour's (1990) taxonomy. In neither of these recent studies did the authors provide explicit reasons for their selection, whilst Shipman et al. (2002) combine three selected taxonomies but provide very limited justification of their approach. The first rationale for the work described here is therefore that existing findings can be more easily contextualised through a better understanding of the relationship between the frameworks employed.

The understanding generated through a review and synthesis of taxonomies can also inform future work, especially if used to direct data collection and analysis. For example, it might inform the development of standardised tools for assessing learner views concerning the relationship between science and religion. I acknowledge that standard tools, and indeed taxonomies, may not always be appropriate. For example, Stolberg (2007) discussed Barbour's typology as a possible framework for her work but found it inadequate for understanding attitudes and instead used a phenomenological approach to ascertain student teachers' perceptions of the relationship between science and religion. Other

authors such as Reich (2010) critique the binary logic underpinning the use of taxonomies of views, arguing that understandings of the relationship between science and religion cannot be neatly categorised. However, I maintain that standardised tools can facilitate the development of a coherent body of research.

I do not intend to imply that categorising views of the relationship between science and religion is unproblematic. Firstly, Smith and Scharmann (1999) note that the distinctions between science and nonscience are not always clear-cut and are often philosophical. Categories may therefore be overlapping or difficult to distinguish empirically and furthermore are likely to shift or develop over time. For example, at a particular point in time individuals may strongly agree with one view without fully rejecting another. Over time, views may change, as shown by McKeachie et al. (2002) who found that students tended to move from a conflict to a reconciliatory view after taking a course in introductory biology. Indeed, it may be that a common pattern is for students to start from a conflict view, then arrive at an intermediate phase of believing they need to decide “which explanation is true” and finally either return to a conflict view or learn to separate the contributions of science and religion or integrate them. A process of this nature would be consistent with the epistemological development scheme proposed by Perry (1970), as well as with Lederman (1995)’s claim that high school students tend to be at a dualistic stage in this scheme and Billingsley et al. (2012)’s finding that school students tend to hold only one view of the relationship between science and religion and are unaware of other views. I return to the issue of the difficulty of categorising views concerning the relationship between science and religion in the development of the tool, where I consider a possible reconciliation of this view with the use of taxonomies. The basis for the work described here is therefore the belief that comparability between studies can be enhanced through both a better understanding of the relationship between taxonomies and the use of a standardised approach to categorising individual views of science and religion in future data collection.

In the following sections, I compare, contrast and synthesise existing taxonomies for the first time. I then show how this analysis supports the development of a simple research instrument for investigating understandings of the relationship between science and religion.

4.3 Comparison and synthesis of taxonomies

The relationship between science and religion has been addressed extensively in the philosophical literature (Alexander, 2007) and has been discussed by a range of philosophers and scientists. I conducted a comprehensive review of the philosophical literature to identify taxonomies of views concerning the relationship between science and religion. In addition to taxonomies considered in the philosophical literature, I reviewed the educational literature for work that referred to each of the philosophical categorisations identified and that provided evidence of learner views according to taxonomies.

During the search of literature, in addition to taxonomies of views concerning the relationship between science and religion, I also uncovered a number of taxonomies focusing on the relationship between scientific and religious explanations for the origins and development of life forms. However, while acknowledging the importance of this topic, I chose to exclude it from the current analysis because I was particularly interested in frameworks that apply to a broader range of issues related to the larger domains of science and religion rather than more specific contexts such as evolution and creationism. I also wished to develop a framework that is relevant for a range of religions, including those where the contexts in which the relationship with science is problematic may differ from those of the monotheistic traditions. Nonetheless, I return to the link between views and understandings of particular contexts such as the relationship between scientific and religious explanations of the origins of life in Section 4.4: Synthesis of Taxonomies in the Philosophical Literature and in Section 4.9: Conclusion.

The search for taxonomies in the philosophical literature led to the identification of five largely independent frameworks: Polkinghorne (1986),

Barbour (1990), Haught (1995), Nord (1999) and Alexander (2007). These taxonomies are proposed by scholars from a range of scientific and religious backgrounds: a theoretical physicist (Polkinghorne, 1986), a professor of religion (Barbour, 1990), a Roman Catholic theologian (Haught, 1995), a philosopher (Nord, 1999) and a biologist (Alexander, 2007). Another taxonomy proposed by McGrath (2010) was considered but not included because it is largely based on Barbour (1990). I also excluded the well-known continuum proposed by Scott (2005) because it focuses specifically on creation and evolution (as noted above). In the educational literature I identified four empirical studies that focused on views concerning the relationship between science and religion (Hokayem and BouJaoude, 2008, Shipman et al., 2002, Taber et al., 2011, Yasri and Mancy, 2012). These studies also contained empirically-validated taxonomies similar to those in the philosophical literature with one additional view proposed by Taber et al. (2011) and Yasri and Mancy (2012). Different terms and definitions are used in these studies and in order to increase the clarity and readability of the paper, I begin my presentation with the philosophical taxonomies, followed by the synthesis of these taxonomies. The synthesis is then considered in conjunction with the empirical studies where the additional view identified from the empirical literature is discussed. A summary of these taxonomies is presented in Table 4.1 and includes the label used to refer to each view and its description.

4.3.1 Polkinghorne (1986)

Polkinghorne (1986) describes four possible ways of relating science and religion under the following section headings: Conflict, Natural Theology, Modes-of-Thought, and One World⁶. Although Polkinghorne does not talk about these in the form of categories, for consistency of discussion, I refer to them here as distinct views.

⁶ In order to distinguish clearly between view labels used by other authors and those used in this taxonomy, I Capitalise views in the existing literature; I use *italics* for the terms used in this synthesis, and both *Capitalisation and Italics* for views included in the research instrument described in this paper.

According to the Conflict view, science and religion seek answers to the same questions but at times provide contradictory responses. Polkinghorne explains that there are two ways of understanding and exploiting these contradictions. One approach is the use of religion to make assertions in an attempt to undermine science. This form of interaction is found in the historical opposition by the Church to the theories proposed by Galileo (heliocentric model) and Darwin (evolutionary theory). The other approach is the use of science to discredit religious claims with the argument that “in the end there is nothing but scientifically discerned reality” (p. 65), a view often referred to as scientism. Within this view, Polkinghorne points out four areas of potential conflict between science and religion: the origins of the universe and life on planet Earth, questions of God’s interaction with the world, debates over miracles described in the Bible and questions regarding the future of life.

In contrast, according to the Natural Theology view, science is a tool that can be used to explore and explain the nature of God: science and religion address the same questions and are thus in harmony. Proponents of this view therefore adopt science to construct religious understandings. Polkinghorne goes further, stating that according to this view, modern scientific discoveries not only explain how natural phenomena occur but also provide pointers suggesting the existence of a supernatural creator or designer. In other words, this view describes a single harmonious reality of God *in* the world, as opposed to the competing realities of God *and* the world described in the Conflict view above. In the Natural Theology view, compatibilities between science and religion are emphasised, while differences and contradictions between the two are not recognised.

According the third view, Modes-of-Thought, Polkinghorne explains that science and religion are concerned with two “radically different kinds of subject matter” (p. 64)⁷. Thus the reality of the world (physical and objective) and the reality of God (spiritual and subjective) can be distinguished. Polkinghorne argues,

⁷ This view is similar to *NOMA* (Gould, 2002).

however, that science and religion seem to share similar characteristics in relation to their procedures for constructing knowledge (epistemology) and their questions of interest (ontology). He points out that “each is corrigible, having to relate theory to experience, and each is essentially concerned with entities whose unpicturable reality is more subtle than that of naïve objectivity” (p. 64). In other words, science and religion often provide answers to similar kinds of questions (e.g. questions of the origins of life) and also show similarities in the processes used to generate ideas and knowledge, especially in their use of experience, analogy and imagination; however, they differ in the focus on the physical or spiritual nature of the subject matter.

The final view is called One World. According to this view, there is only one reality, but science and religion explore different aspects of it. More specifically, neither science nor religion holds absolute authority with respect to truth, but each works in its own realm in search of its own truth, and ultimately these combine to form a richer understanding of reality. From his own theistic standpoint, Polkinghorne argues that the aim of religious doctrine is to explain the source of rational order and structure of the universe and thus the aims of science and religion are aligned.

4.3.2 Barbour (1990)

In *Religion in an Age of Science* Barbour (1990) discusses four possible ways of relating science and religion: Conflict, Independence, Dialogue and Integration. His analysis relies more heavily on the epistemology and metaphysics of each than that of Polkinghorne.

Barbour’s first view of the relationship between science and religion, like that of Polkinghorne (1986), is a Conflict view. However, he considers the main causes of the conflict rather differently. Polkinghorne (1986) emphasises the opposition between the explanations provided by scientific and religious enterprises, whereas Barbour focuses on the metaphysical and epistemological distinctions between the two systems. The extreme positions are referred to as *scientific materialism* and *biblical literalism*. Barbour points out that these two schools of thought share characteristics that make it sensible to categorise them

in the same group. Firstly, proponents of both systems believe that there are serious contradictions between newly discovered scientific explanations and traditional religious beliefs. Secondly, both groups seek a single, sure foundation of knowledge, such that differing explanations are inevitably considered to be in opposition (Barbour, 1990) and that it is necessary to choose between them. Barbour argues that both extreme positions are based on misconceptions, or at least on narrow interpretations of science. The starting point of scientific materialism is the scientific process, but in contrast to other positions on the place of science, scientific materialism consists in the belief that scientific methods are the *only* way to uncover knowledge and that matter is the only reality in the universe. In contrast, biblical literalism refers to a school of thought that interprets the Bible (or other liturgical texts) as literally true, and thus, wherever it makes claims about matters of science, holds that biblical statements are also scientifically true.

Barbour's second view is Independence, according to which science and religion are considered to be entirely independent and autonomous. According to this view, Barbour (1990) explains that science and religion are different in two main ways: contrasting methods and differing languages. Methodologically, it is claimed that science and religion can be differentiated by their focus on two different realities: matter and soul. Science is based on human observation and reasoning and aims to explain observable data through empirical studies. In contrast, religion relies on the authority of divine revelation and focuses on the experience of an "inner life" and an understanding of the meaning and purpose of being, achieved through the use of both symbolic and analogical messages provided in sacred books. The methods also differ in that the scientific realm of objective detachment is one in which individuals conduct impersonal investigation of observed objects (I-It relationship), whereas the religious realm focuses on subjective involvement in which the relationship is between human beings and the Divine (I-Thou relationship). Another way to separate science from religion is to focus on the communicational functions of scientific and religious "languages". Barbour (1990, pp. 13-14) explains that scientific language, in the form of theories and research questions, is "a useful tool for summarising data, correlating regularities in observable phenomena, and

producing technological applications” in contrast to religious language which is used to “recommend a way of life, to elicit a set of attitudes, and to encourage allegiance to particular moral principles”. According to Barbour, we should not expect science to “do jobs for which it was not intended, such as providing an overall worldview, a philosophy of life, or a set of ethical norms”.

In Barbour’s opinion, Independence is problematic as a way of relating science and religion because it ignores wholeness and any interconnectedness between science and religion. He therefore proposes the Dialogue view, according to which science and religion have indirect interaction. This view acknowledges that the two disciplines are independent; however, there are significant areas of positive “indirect” interaction among them. Barbour focuses particularly on two aspects of contact: “boundaries questions” and methodological parallels. Pointing to examples where science and religion have been brought together, Barbour explains the role of the Judeo-Christian culture in the development of scientific knowledge in Western history. It is understood that the doctrine of biblical creation contributed to the initiation of scientific study for many Westerners. For example, religion provided a reason for scientists such as Newton and his contemporaries to investigate the contingent and rational order of the world and the universe. In addition, Barbour argues that although it is possible, under assumptions of positivism, to draw distinctions between scientific and religious approaches to gaining knowledge about the world, there are nonetheless similarities: “clearly, religious beliefs are not amenable to strict empirical testing, but they can be approached with some of the same spirit of inquiry found in science” (1990, p. 21). He also acknowledges that both scientific theories and scriptural texts are laden with interpretation and that models and analogies are used heavily in both science and religion. Ultimately, Barbour suggests, one cannot compartmentalise science and religion and Dialogue is the way in which scientific and religious communities come together by allowing them to interact indirectly through conversations.

Finally, Barbour (1990) notes that scientific and religious knowledge can be more directly integrated into a complete reality in which each discipline can illuminate the other. He calls this view of the relationship Integration. He

outlines three ways for integrating science and religion in which different directions of the interaction between the two are discussed. First, *natural theology* is an attempt to use human reasoning based on scientific findings to confirm religious knowledge. It claims that evidence of orderliness and intelligibility of nature heightens our awareness of the existence of God as Creator. Unlike natural theology, *theology of nature* does not start from science but from “religious experiences and historical revelation” (1990, p. 26). It adopts scientific knowledge to broaden understandings of religious texts in order to make these more compatible with science; for example, in this approach some traditional doctrines based on literal interpretations of religious texts are reformulated in the light of scientific explanations. Barbour’s third route of direct interaction between science and religion is *systematic synthesis* in which “both science and religion contribute to a coherent worldview elaborated in a comprehensive metaphysics - the search for a set of general categories in terms of which diverse types of experience can be interpreted” (1990, p. 28)..

4.3.3 Haught (1995)

In *Science and Religion: from Conflict to Conversation* Haught (1995) also provides four principal ways of relating science and religion: Conflict, Contrast, Contact and Confirmation. He gives the Conflict view as his first explanation of this relationship and classifies this view into two subcategories: a first version in which proponents argue that religious claims are untrue and a second in which proponents argue that scientific claims are false. Those in the first group maintain the idea that religion “cannot demonstrate the truth of its ideas in a straightforward way whereas science can” (Haught, 1995, p. 10) and that religious knowledge relies heavily on faith and is highly subjective. The second group sees conflict between their belief and scientific explanations when these do not correspond with the Bible, and in this case proponents claim that science is wrong, also arguing that religion offers meaning in contrast to science which is “spiritually corrosive” because it causes “emptiness and meaninglessness” (1995, p. 12). Haught argues that this view of the relationship arises from the invasion of science in the religious arena and vice versa.

Haught's second view of the relationship is the Contrast view. According to this view, religion and science "have no business meddling in each other's affairs in the first place" (Haught, 1995, p. 13). More specifically, he explains that both science and religion are valid within their own well-defined "sphere of inquiry" and that "we should not judge religion by the standards of science, nor vice versa, because the questions each asks are so completely disparate, and the content of their answers so distinct, that it makes no sense to compare them with each other" (p. 12). Science deals with the natural world, causes of things, solvable questions and particular truth, but religion focuses on ideas lying beyond the empirical world, including meaning and purpose, unsolvable mysteries and the ultimate truth of life. One would therefore be remiss to judge religion using scientific standards and vice versa. Haught's analysis thus describes the differences between science and religion primarily in relation to the questions that they address. He also suggests that the Contrast view can be considered as the "safest" way of relating science to religion because no connection is made. Therefore, no conflict exists.

The third view proposed is the Contact view. In Haught's (1995) view, the ideal would be to completely distinguish between science and religion according to the description of the Contrast view. However, in the real world, it is not easy to compartmentalise science and religion since theologians sometimes refer to science and scientists sometimes refer to religious views. Historically, for example, Christianity has contributed to the advancement of science through generating motivation for scientists, and in turn scientific progress has sometimes contributed to theologians' reformulations and reinterpretations of scripture. An example of the latter can be found in the shift in the position of the Catholic Church resulting from the development of evidence for evolution. In 1996 Pope John Paul II declared that evolutionary theory had been progressively accepted by researchers following a series of discoveries in various fields of knowledge. Thus, he accepted evolution as a fact. He argued that it is important to "draw attention to the need of a rigorous hermeneutic for the correct interpretation of the inspired word. It is necessary to determine the proper sense of Scripture, while avoiding any unwarranted interpretations that make it say what it does not intend to say" (Pope John Paul II, 1996). Making his

argument more explicit to the case of evolutionary theory, the Pope referred to Pius XII's 1950 encyclical, *Humani Generis*, which had already explained that "if the human body takes its origin from pre-existent living matter, the spiritual soul is immediately created by God" (Pope Pius XII, 1950). This explanation suggests that the Pope's interpretation of human origins as depicted in the Bible is interpreted in terms of evolutionary theory and research, and specifically evolution is theologically unproblematic if the scripture on divine creation (i.e. Genesis) is interpreted as relating to the direct creation of the *soul* rather than the direct creation of the physical body. This leads to a Contact relationship between science and religion in which the communities associated with each seek for positive consonance with one another through internal conversations or conversations between those belonging to the two communities. Haught (1995, p. 18) explains that "the term 'contact' implies coming together without necessarily fusing. It allows for interaction, dialogue, and mutual impact but forbids both conflation and segregation". He believes that by adopting the Contact view, scientists can deepen their understanding and appreciation of the universe and life through religious faith, and similarly religious ideas can be broadened through the discoveries of science. However, Haught explains that according to this view scientific knowledge is not used to imply religious truth (e.g. confirming the existence of God through the complexity of science) but that scientific discoveries gain additional meaning for religious believers through consideration of their place within a religious framework.

Finally, Haught (1995) proposes his preferred view, Confirmation, according to which religion serves to strengthen and support science. To him, religion confirms science in a very deep way as it claims that "the universe is a finite, coherent, rational, ordered totality, grounded in an ultimate love and promise", and this "provides a general vision of things that consistently nurtures the scientific quest for knowledge" (p. 22). In other words, religion confirms and even undergirds scientists' epistemological trust in the ultimate coherence and rationality of the universe.

4.3.4 Nord (1999)

Nord (1999) also categorises the relationship between science and religion into four possible views but combines these differently. Like the previous authors, he refers to the Conflict view, which he divides into two distinct subcategories. In the first of these, Religion Trumps Science, the view is that “when science and religion conflict, only religion provides reliable knowledge. It is through inerrant scripture or religious tradition that we come to know the ultimate truth about nature” (p. 29). In the second subcategory, Science Trumps Religion, wherever science and religion conflict, “only science provides reliable knowledge”. Furthermore, “it is through the methods of science that we learn the ultimate truth about nature”. According to this view, it is believed that whatever cannot be explained by science literally does not exist. Religion therefore has no role in uncovering reality. Nord states that this view is usually known as scientism, naturalism or scientific materialism.⁸

The third view is called Independence and proponents of this view claim that “science and religion cannot conflict because they are incommensurable: each has its own methods; each has its own domain [...] One common expression of this view is that science asks objective “how” questions, while religion asks personal “why” questions” (1999, p. 29). Thus science is fully authorised to explore physical reality but has no role in answering questions about why things exist. In contrast, religion seeks the meaning and purpose of life but should not attempt to explain the mechanisms of nature.

Finally, Nord (1999, p. 30) describes a view in which “science and religion can conflict [they are different in this sense] and can reinforce each other [they complement each other], for they make claims about the same world”, arguing that a “fully adequate picture of reality must draw on - and integrate - both”. This view of the relationship is called Integration. It should be pointed out that

⁸ Smith (2010a) explains that some authors distinguish between philosophical and methodological materialism, the former referring to a philosophical claim that the supernatural does not exist, whereas the latter does not necessarily deny the supernatural but only that this is outside the realm of science. In these statements, Nord is presumably referring to ontological materialism.

although the term *integration* is used by both Nord and Barbour, their explanations are somewhat different. Barbour's Integration refers to the attempt to combine science with religion where both explain the same aspects of reality. In contrast, Nord's Integration allows for differences between the domains of application of science and religion. Further, Nord (1999) claims that understanding science can benefit from knowledge from the religious arena and that religious ideas can often be strengthened through a grounding in scientific findings. In other words, science and religion play different roles in generating knowledge and understanding in their respective domains, but ultimately, it is only through the combination of these forms of knowledge that we come to understand the world in its full complexity.

4.3.5 Alexander (2007)

Alexander (2007) describes four views on relationship between science and religion. His first view is Conflict and in this view explanations from science and religion can provide incompatible answers to the same fundamental question. Alexander (2007, p. 2) argues that "conflict tends to occur when either science or religion adopts "expansionist" attitudes, purporting to answer questions that rightly belong to the other domain of enquiry". He points out that this view remains popular in the public domain.

The second view in this framework is called NOMA after the "Non-Overlapping Magisteria" view proposed by Stephen Jay Gould (2002). In this view, science and religion deal with different domains of reality. Specifically, Gould (2002) claims that science and religion focus on different fundamental questions: the magisterium of science focuses on empirical data; the magisterium of religion covers questions concerning ultimate meaning and moral value. These two domains do not overlap by definition, thus there is no conflict between the two. This view relates to Moore (1984)'s discussion of "science as a way of knowing" (SAAWOK). In SAAWOK, science is viewed as only one means of learning about the world; supernatural phenomena are not necessarily denied but are not studied by science. Smith (2010b) explains that "both NOMA and SAAWOK recognize that science is but one possible way of knowing" (p. 541), thus leaving room for faith as another source of knowledge.

Alexander's third view is the Complementary view. According to this view, "science and religion address the same reality from different perspectives, providing explanations that are not in any kind of rivalry to each other, but rather are complementary" (2007, p. 4). Proponents of this perspective often argue that putting faith and scientific reason together enables us to understand the whole range of reality (e.g. Berry, 2007).

The final view identified by Alexander (2007) is Fusion. In this view, there is no clear distinction between the kind of knowledge provided by scientific and religious explanations because both focus on the same reality and provide the same knowledge. Alexander (2007, p. 3) explains that those who take this perspective "tend to blur the distinction between scientific and religious types of knowledge altogether, or attempt to utilize science in order to construct religious systems of thought, or vice versa".

Authors	View names	Descriptions
Polkinghorne (1986)	Conflict	Science and religion make (at times) contradictory assertions about a single reality.
	Natural theology	Science and religion make the same claims about a single reality and science helps to explain the nature of God.
	Modes-of-thought	Science and religion deal with two different kinds of subject matter (physical and objective versus spiritual and subjective).
	One world	Science and religion consider different aspects of a single reality to create a richer understanding.
Barbour (1990)	Conflict	Two forms: either matter is the only form of reality and knowledge is gained only through the scientific method; or alternatively, religious knowledge is the only true source of knowledge.
	Independence	Science and religion differ in two ways: their approaches to arrive at knowledge and their communicational functions.
	Dialogue	Science and religion are mutually supportive in directing and underpinning the human quest for knowledge.
	Integration	Three ways of integrating science and religion to form a single explanation of the world: natural theology, theology of nature, and systematic synthesis.
Haught (1995)	Conflict	Science and religion are fundamentally incompatible and one makes claims that are positively or normatively “wrong”.
	Contrast	Science and religion focus on different kinds of questions and each is valid in its own realm.
	Contact	Science and religion interact indirectly through conversations among scientists and theologians.
	Confirmation	Religion undergirds science by providing a rationale for the scientific assumption of a coherent and ordered universe.
Nord (1999)	Science trumps religion	When science and religion are in conflict, only religion is correct.
	Religion trumps science	When science and religion are in conflict, only science is correct.
	Independence	Science and religion have their own methods and domains of application.
	Integration	Science and religion both contribute knowledge and a full understanding of reality relies on understandings from both.
Alexander (2007)	Conflict	Science and religion are fundamentally contradictory.
	NOMA	Science and religion consider two separate aspects of reality that do not overlap.
	Complementary	Science and religion consider different aspects of the same reality that must be combined to understand the richness of reality.
	Fusion	Science and religion are completely integrated into a united reality.

Table 4.1: Summary of views discussed in the philosophical literature, with descriptions

4.4 Synthesis of taxonomies in the philosophical literature

This review of published taxonomies of the ways of relating science and religion demonstrates that there are overlaps as well as distinctions amongst the taxonomies. This suggests that selecting only one categorisation for the purposes of framing a research study in the educational sphere might be insufficient. In this discussion I compare and contrast the five taxonomies so as to construct a synthesis and comprehensive account of ways of relating science and religion. Because different terms are used by different authors to describe similar views, I highlight the chosen terms for these views in bold (see Figure 4.1).

I first note that the views can be grouped into those that consider science and religion as incompatible and those that permit compatibility between the knowledge systems. Focusing first on the *incompatible* group, the philosophical literature considers only one main view, the *conflict* view (the additional *Compartment* view, drawn from the educational literature, is discussed below). In this view, two stances are proposed: one where science takes priority over religion and one where the reverse is true. In relation to any questions where science and religion appear to provide different answers (e.g. the origins of the universe and life), according to a *Science Trumps Religion (STR)* view, only science provides accurate answers. In contrast, according the *Religion Trumps Science (RTS)* view, scientific explanations are claimed to be erroneous if they conflict with religious explanations. This relatively straightforward view is included in all taxonomies of the relationship between science and religion considered above.

Turning to the group of *compatible* views, this cluster contains two main subcategories: in the first, one might find science and religion compatible because it is possible to separate them in line with a *contrast* view; in the second, it may be possible to create *consonance* and combine them into a single entity using one of a range of processes. There are two forms of *contrast* view in the literature. Although most authors agree that science and religion can be viewed as two

different worlds (or realities) with no epistemological, ontological or methodological connections between the two, Polkinghorne (1986) argues that this view is theoretically flawed. To him, it is possible only to separate scientific (objective) and religious (subjective) centres of focus, while the epistemological, ontological and methodological aspects of science and religion are interrelated.

When science and religion are perceived as in *consonance* and thus providing knowledge relating to a single reality, views concerning the relationship become more complex and are generally less clearly delineated in the philosophical literature. Nonetheless, two general views can be found here: *Complementary* and *Coalescence*. In the *Coalescence* view, science and religion are considered to deal with the same aspects of the same reality, but neither contradictions nor differences between the two are considered to exist. This view is thus consistent with the Fusion view of Alexander (2007). Alexander (2007) adopted a relatively broad definition of this view whereby science and religion deal with the same questions and provide the same answers. This definition is compatible with the application of science to the construction of religious ways of understanding and vice versa, which is assumed to be common among Eastern religious traditions (Alexander, 2007). In contrast, in a *Complementary* view, differences between science and religion are accepted but do not lead to rivalry between the two, serving instead to complete missing components. An example may be found in the use of religious frames along with the findings of science to construct moral positions. For example, individuals may develop a position on abortion by combining religious understandings of life and its meaning with scientific findings from embryology such as those relating to disease detection *in utero*. In other words, those subscribing to a *Complementary* view consider science and religion as separate but sometimes combine scientific and religious knowledge to inform their opinions and decision making.

I suggest that the *Complementary* view consists of three main subcategories depending on how one kind of knowledge is used to support the other. The first subcategory is termed *science supports religion (SSR)*. This view of the interaction

does not combine scientific and religious knowledge through the blending process of *Coalescence*; instead, it seeks the use of science to broaden religious understandings either by adopting scientific knowledge to appreciate divine works according to *natural theology* (Polkinghorne, 1986; Barbour, 1990) or by revising religious doctrines in the light of scientific advancement according to *theology of nature* (Barbour, 1990). Haught's Confirmation is an example of a second subcategory that I term *religion supports science (RSS)* in which Haught provides an argument for one-way support flowing from religion to science in that "a religious vision of reality inherently fosters the scientific exploration of the cosmos" (p. 22). The third subcategory shows *mutual support* between science and religion through either the *direct* use of one discipline to strengthen the other according to One-World (Polkinghorne, 1986), *systematic synthesis* (Barbour, 1990), Integration (Nord, 1999) or Complementary (Alexander, 2007, Yasri and Mancy, 2012) or the *indirect* contact between the two sets of knowledge through historically interactive events, a position assumed to be common in the Western world, as discussed by both Barbour (Dialogue) and Haught (Contact).

In both Barbour's Dialogue view and Haught's Contact view, science and religion interact indirectly and are combined through their role in broadening human understandings. However, these views are not positions in the same way as the other views described, and although they feature in Figure 4.1, I do not believe that they should form part of the taxonomy itself. Specifically, it is entirely possible to acknowledge dialogue between science and religion in the development of both while simultaneously holding any of the other positions. For example, an individual may believe in the truth status of scientific findings more strongly than religious claims (*STR*), even while acknowledging a role for indirect interaction between science and religion, currently and throughout history. In other words, I take the position that Dialogue and Contact relate to a different dimension of the relationship between science and history, one that better describes the processes of interaction from a third-party or historic perspective, rather than one that relates to personal epistemology.

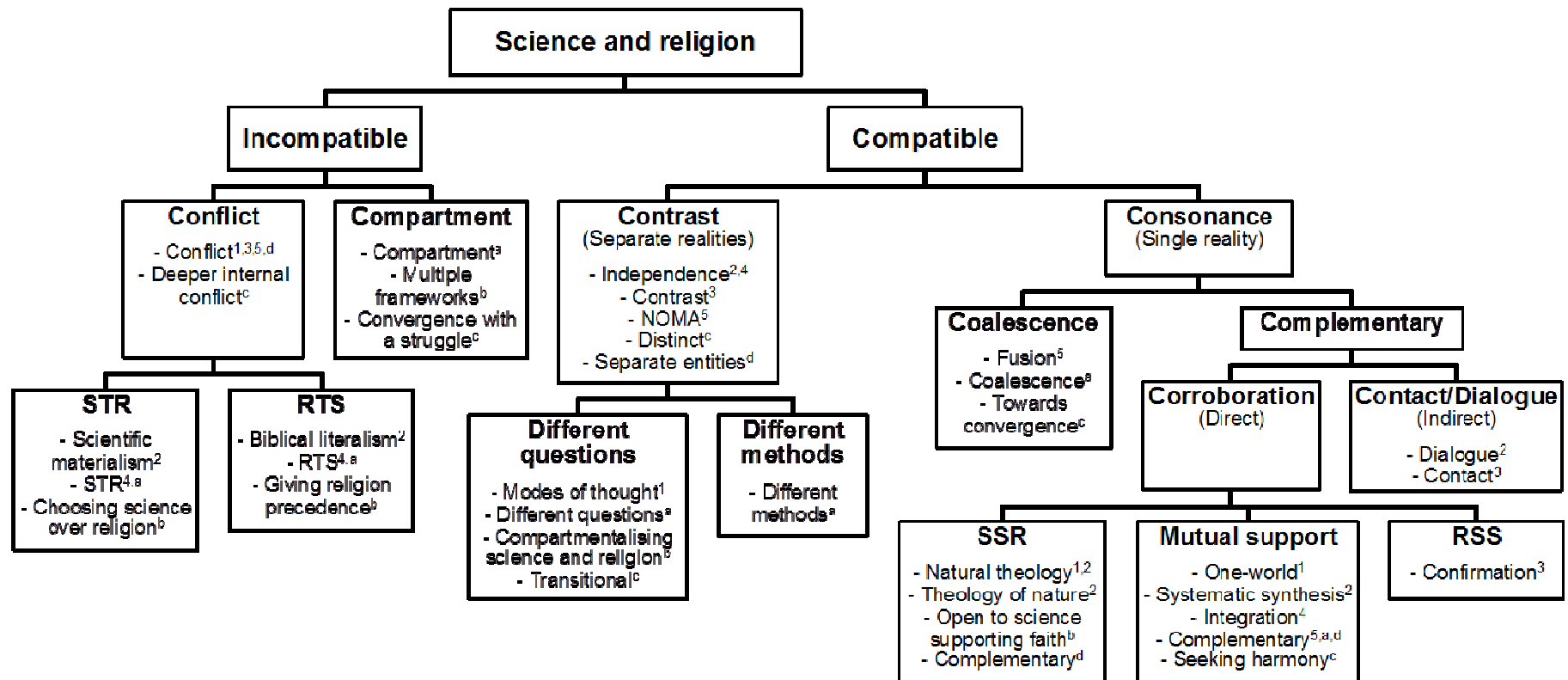


Figure 4.1: Summary of the correspondence between published views on the relationship between and religion. Category names used in this paper are shown in bold and corresponding views from other work are provided below the category names. Citations labeled 1-6 are taken from the philosophical literature and a-d from the educational literature. (1 = Polkinghorne (1986), 2 = Barbour (1990), 3 = Haught (1995), 4 = Nord (1999), 5 = Alexander (2007), a = Yasri and Mancy (2012), b = Taber et al., (2011), c = Shipman et al. (2002) and d = Hokayem & BouJaoude (2008). (STR = science trumps religion; RTS = religion trumps science; SSR = science supports religion; RSS = religion supports science)

4.5 Reanalysis of views in empirical studies

In this section the synthesised taxonomy is considered in conjunction with taxonomies in four empirical studies (Hokayem & BouJaoude, 2008; Shipman et al., 2002; Taber et al., 2011; Yasri & Mancy, 2012) in order to ensure applicability as well as comparability. First, this is straightforward in the case of the *conflict* because this category is included in all of the taxonomies identified in educational work, although different terms are used (see Figure 4.1). Specifically, while Shipman et al. (2002) and Hokayem and BouJaoude (2008) broadly classify this view based on perceived incompatibilities between science and religion, Taber et al. (2011) and Yasri and Mancy (2012) specifically focus on two different forms of incompatibility, namely Nord's Religion Trumps Science and Science Trumps Religion.

In addition to the *conflict* views, an additional incompatible view is found in Yasri and Mancy (2012) and is referred to as *Compartment*. Evidence for this view is also provided by Taber et al. (2011) who refer to it as Multiple Frameworks and by Shipman et al. (2002) who refer to it as Convergence with a Struggle. Individuals holding this view consider that there are conflicts and inconsistencies in the explanations provided by science and religion but are unable to decide which should take priority. As a result, those who take this view adopt the explanatory frameworks of science and religion on a contextual basis. For example, as learners, they adopt a religious framework in religious education classes and a scientific framework in science lessons. Given that this view lacks commitment to a particular relationship, it is perhaps unsurprising that the *Compartment* view has not been discussed in the philosophical literature. However, the above studies indicate that it is important to include this view in research.

Third, all of the taxonomies based on the educational studies include *contrast* views, although various dimensions of the view are presented. Both Shipman et al. (2002) and Hokayem and BouJaoude (2008) present the distinction between science

and religion in a holistic manner similar to the distinction made by Barbour (1990), Haught (1995), Nord (1999) and Alexander (2007). This view is referred to as Distinct by Shipman et al. (2002) and as Separate Entities by Hokayem and BouJaoude (2008). Nonetheless, Yasri and Mancy (2012) explain that within the Contrast view, one might consider that science and religion are different only in their focus (*Different Questions*); however, one might also distinguish them not only on the basis of the domains of knowledge generated by scientific and religious enterprises but also by the means employed to reach that understanding (*Different Methods*). Yasri and Mancy (2012) also show that this philosophical distinction can be seen among high school students. The *Different Methods* view is consistent with Polkinghorne's Modes-of-Thought. In addition, it is also demonstrated in two other empirical studies (i.e. Taber et al.'s Compartmentalising Science and Religion and Shipman et al.'s Transitional). It should be noted here that although Shipman et al. (2008) distinguish Distinct from Transitional learners, in the synthesised framework, the two are very similar in terms of their view of the relationship between science and religion. Specifically, individuals who hold Transitional views are those who separate science from religion on the basis of specific questions, whereas Distinct thinkers are those who distinguish between the two in a holistic way. In fact, the Transitional view is classified by Shipman et al. by referring to Gould's (2002) NOMA view, which is also used directly by Alexander (2007).

Turning to *consonance* views, the synthesised taxonomy captures all of the remaining views proposed in the educational literature. In the fourth view, the term *Coalescence* is taken from Yasri and Mancy (2012) who describe it in a similar way as Alexander's Fusion (science and religion deal with the same questions and provide the same answers). This view is also consistent with Shipman et al.'s Towards Convergence in which science and religion are believed to constitute a harmoniously united knowledge. In the fifth category, the *Complementary* view is also found in all four studies, although minor variations can be observed. Yasri and Mancy's Complementary and Shipman et al.'s Seeking Harmony (a form of convergent thinking) describe science and religion as mutually supporting. Taber et

al.'s Open to Science Supporting Faith corresponds to SSR. Both forms of complementarity are also presented in the study of Hokayem and BouJaoude (2008). Specifically, one group of students was classified based on their acknowledgement of different domains of reality in which science and religion mutually contribute (*mutual support*) and the other group based on their reconciliatory view through the use of science to expand and deepen religious knowledge (SSR). Although I acknowledge that these different ways of perceiving the complementarity between science and religion exist based on my own work with students, I grouped these together. Trained theologians, philosophers and scientists may be able to distinguish clearly between the directions of support between science and religion of the *Complementary* view, but these distinctions may be less transparent or relevant to high school and undergraduate learners.

The relationship between the main views discussed here is provided in Figure 4.2, which shows those included in the taxonomy coloured in grey. A dichotomous key of the kind used in the biological sciences that can be used to identify views was developed and is included in Appendix G

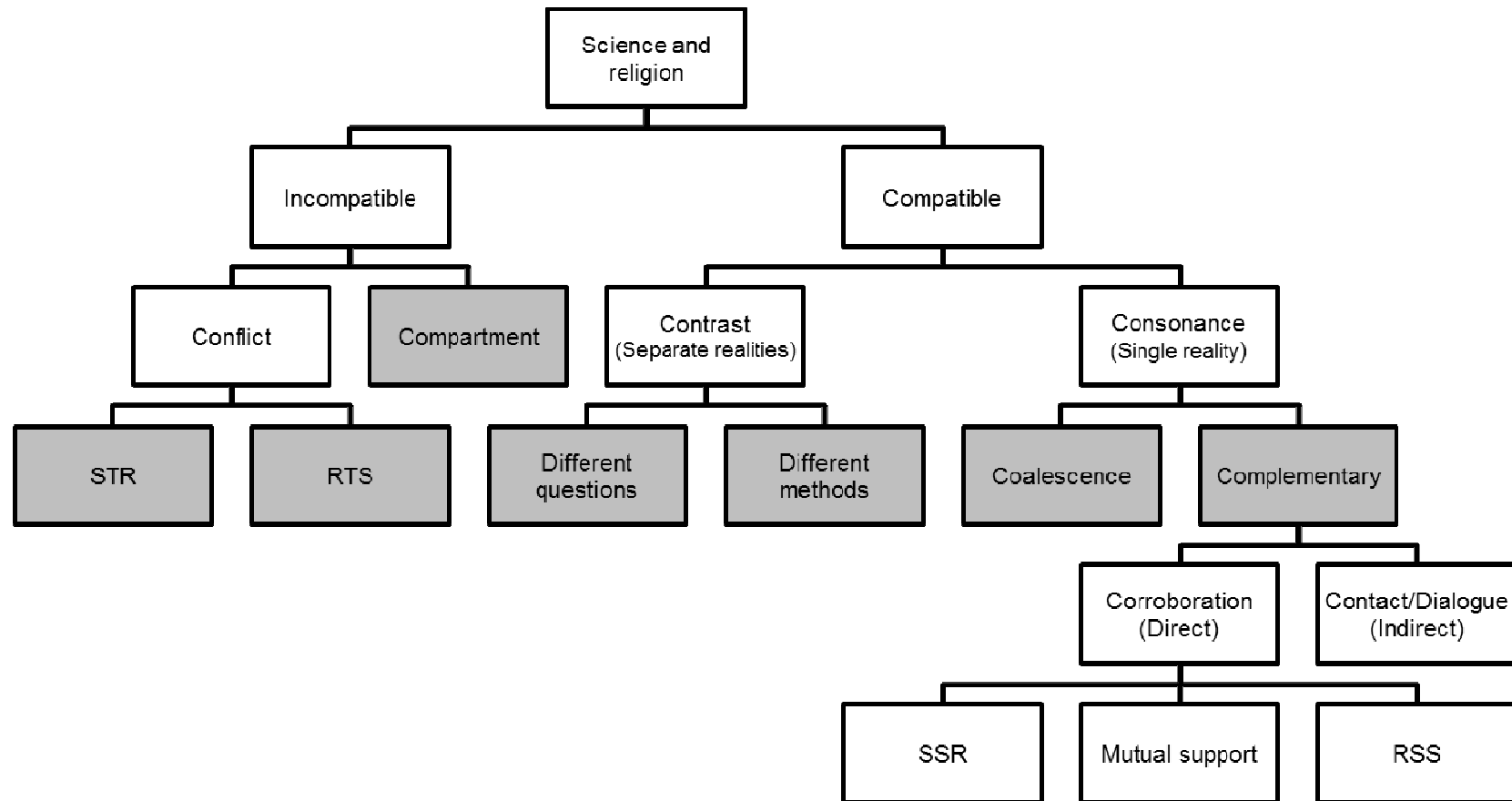


Figure 4.2: Classification of views of the relationship between science and religion. Grey-shaded views are explicitly included in the empirically-oriented taxonomy. (STR = science trumps religion; RTS = religion trumps science; SSR = science supports religion; RSS = religion supports science)

4.6 Development of a research tool

As explained previously, the above synthesis of views can be useful to educational research not only because it facilitates the comparison of earlier studies, but also because it supports the development of tools for future data collection and analysis that include all relevant views. Applying the synthesis to review all existing studies in science education is beyond the scope of this paper; its application the present work is to underpin the development of a research tool. One way in which the comparability of studies can be supported is through the development of a standardised research instrument to ascertain individual views concerning the relationship between science and religion, and it is on this application that I now focus. Specifically, I now describe the process by which I developed and tested a research tool designed to ascertain learner and teacher views concerning the relationship between science and religion.

I wished to develop a standardised research instrument in the form of a simple set of questions that would allow individuals to identify their own view in relation to the classification scheme just outlined. The categories of response to include in the questions thus arose naturally from the discussions above.

To determine the wording of survey items and to gain confidence in their intelligibility for the targeted participants, I used student narratives drawn from an earlier interview study (Yasri and Mancy, 2012) conducted with high school students (aged between 15 and 18). Statements were selected from interviews on the basis of clarity and representativeness of the view from the participant interviews. Minor rewordings were made, and hesitations and other verbal signals were removed to form readable statements. To enhance the validity of the questionnaire, the academic heads of the Departments of Science-Mathematics and Religion in a large Thai primary and secondary school⁹ were asked to review the questionnaire, judge the degree to which it measures the target construct, and make suggestions for improvement. Four doctoral

⁹ This school covers educational levels spanning the ages 6 to 18.

candidates and two Master of Science students in science education at the University of Glasgow were asked to provide the same input. These processes resulted in some minor rewording. A similar process is described in Brem et al. (2003) in the development of their questions relating to learner views on the relation between evolution and creation. The response categories are shown in Table 4.2.

Once response categories were determined, I considered the best possible way to elicit participant opinions about the relationship between science and religion. Given discussions in the literature regarding the possibility that an individual may hold more than one view concurrently (Reich, 2010), I wished to allow participants the opportunity to demonstrate agreement with more than one view. In order to achieve this, I designed the questions to include a Likert scale in response to which individuals rate their level of agreement from strongly agree to strongly disagree with each of the views. Respondents also have the option to add their own alternative view at the end of the survey if they desire (see Appendix A). The instrument therefore allows us to test Reich's (2010) assertion of concurrent views.

There were also several reasons to ask participants to indicate the view which best describes their viewpoint. Firstly, for confirmatory purposes, I believed that it would be beneficial to verify that individual selections of a preferred view corresponded to the view or views with which agreement was highest in the Likert section of the questions. Consequently, the tool has the potential both to elicit opinions towards all published views of relating science and religion and to identify each respondent's choice of the view that best reflects his/her personal view.

The final goal was to develop a tool that is brief, relatively easy to complete and appropriate for use in a wide range of religious and linguistic contexts. These considerations were important in supporting replication of studies with different samples in order to compare results across educational contexts, as well as future longitudinal research. The instrument currently exists in English and in Thai and has been employed in the UK among a primarily Catholic

population of undergraduate students, in Thailand among a sample of high school students comprising mostly Buddhists and Christians, and among an undergraduate sample of Sunni Muslims in Pakistan. I call this tool the *Science and Religion Self-Identification Inventory (SRSII)*, pronounced “sir - see”); the English version is provided in Appendix A and the Thai version is available from the authors.

View	Description
Compartment	Some aspects of science appear to conflict with religion but I do not really understand the conflicts.
Conflict (STR)	Some aspects of science appear to conflict with religion. When there are different answers to the same questions, I think only science provides true answers.
Conflict (RTS)	Some aspects of science appear to conflict with religion. When there are different answers to the same questions, I think only religion provides true answers.
Contrast (Questions)	Science and religion do not conflict because their role is to answer different questions (e.g. science deals with questions about the physical universe, while religion addresses questions of ethics, value and purpose).
Contrast (Methods)	Science and religion do not conflict because they construct knowledge in different ways (e.g. scientific knowledge is constructed through testing explanations, while religious knowledge is constructed by interpreting religious texts).
Coalescence	It must be possible to combine science and religion together because they provide the same answers to the same questions.
Complementary	Science and religion are complementary. Both are useful to understand all aspects of life.

Table 4.2: Summary of selected view labels in the proposed empirically-oriented taxonomy, with descriptions.

4.7 Usefulness, Reliability and Validity of *SRSII*

I now consider the usefulness, reliability and validity of the Science-Religion Self-Identification Inventory. In the discussions below, I refer to three studies

carried out using the inventory. These were conducted in the United Kingdom, Thailand and Pakistan and that involved respondents of a range of religious beliefs, educational backgrounds, age groups and genders. Other findings related to Reich's assertions that individuals may hold multiple views and responses to non-preferred views are reported elsewhere (in preparation). The characteristics of the study populations are provided in Table 4.3.

Characteristic	Thai study	Scottish study	Pakistani study
Setting	Thai students attending a course on evolution at a Christian high school	Students engaged in undergraduate initial teacher education attending a Scottish university	College students studying for a BSc in Biology
Sample size	327	86	173
Educational level	High school levels	Undergraduate levels	Undergraduate levels
Educational division	Grade 10 (35.2%) Grade 11 (26.6%) Grade 12 (38.2%)	Year 2 BEd (32.6%) Year 4 BEd (67.4%)	Year 1 BSc (41.6%) Year 2 BSc (58.3%)
Age range	15-18 (mean 16.7)	18-45 (mean 22.9)	17-21 (mean 18.9)
Faith/religion	Buddhist (66.7%) Protestant (27.8%) Agnostic (1.8%) Catholic (1.2%) Undecided (1.2%) Atheist (0.6%) Muslim (0.6%)	Catholic (80.2%) Protestant (8.1%) Church of Scotland (3.5%) Church of England (2.3%) None (2.3%) Agnostic (1.2%) Others (2.4%)	Sunni Muslim (92.3%) Shiite Muslim (1.7%) Ahle-Hadith (4%) Christian (1.2%) No response (0.6%)
Gender	Male (100%)	Male (9.3%) Female (90.7%)	Female (100%)

Table 4.3: Characteristics of study samples

As an indicator of reliability, internal consistency was verified via the correspondence between responses to the two parts of the instrument, namely

in the relationship between respondents' preferred view and their levels of agreement with the statements summarising the various views. In all samples, all response categories for preferred view attracted at least one response, although the distribution of responses differed between samples (Table 4.4 shows the distribution of preferred views). In the Thai sample, 84.4% of the respondents chose as their preferred view either the view for which they had provided the highest level of agreement in the Likert section (100 respondents or 30.6 %) or one of the views with highest agreement where two or more views shared the highest level of agreement for that individual (176 respondents or 53.8%). Among the Scottish and Pakistani samples, the corresponding percentages were 83.7% and 81.5% respectively. For illustrative purposes, the full data on the distribution of levels of agreement for the Thai sample is provided in Appendix H.

Because of the findings from interviews I carried out as part of another project, as well as the findings of McKeachie et al. (2002) and Shipman et al. (2002) which indicate that some individuals may change their view of the relationship between science and religion over time, I chose not to conduct a test-retest reliability check.

Views of the relationship		Thai study (%)	Scottish study (%)	Pakistani study (%)
Conflict	Science trumps religion	27 (8.3)	8 (9.3)	2 (1.2)
	Religion trumps science	11 (3.4)	4 (4.7)	69 (39.9)
Compartment		40 (12.2)	5 (5.8)	1 (0.6)
Contrast	Different questions	72 (22.0)	10 (11.6)	5 (2.9)
	Different methods	26 (8.0)	8 (9.3)	11 (6.4)
Coalescence		41 (12.5)	3 (3.5)	9 (5.2)
Complementary		106 (32.4)	43 (50.0)	71 (41.0)
Alternative view(s)		4 (1.2)	1 (1.2)	0 (0)
Other response		0 (0)	4 (4.7)	5 (2.9)
Total respondents		327 (100)	86 (100)	173 (100)

Table 4.4: Summary of preferred views (based on the single item "preferred view" selection) among the three samples

In addition to the considerations of validity discussed in Section 6 above, I checked internal consistency of responses. One method for checking validity of the *SRSII* is to determine the degree to which individuals are able to select a preferred view or whether they found it necessary to compose their own alternatives in the space provided in the open-ended question (item H in question 1, see Appendix A). In this analysis less than 2% of both the Thai and the Scottish respondents composed their own statement (a summary is shown in Table 4.4). To illustrate how the “other” category was used, the alternative views indicated by Thai participants are provided in Table 4.5 (data from other samples are not shown, but similar patterns emerged).

Additional statements	Identified views
1. There is no relationship between the two.	Contrast
2. Science is about the observable truth whereas religion is only an invented tool to control people’s morality.	Contrast
3. Science and religion have questions that they are unable to answer	Contrast
4. Science never teaches us to be a better person	Contrast
5. Science provides similar answers as religion on key questions.	Coalescence

Table 4.5: Alternative statements provided by Thai participants

Although a small number of participants chose to provide additional statements of the relationship, Table 4.5 shows that with the exception of statement 4, their suggestions actually seem to fit well with the existing categories. Although statement 4 is somewhat ambiguous, cross-checking this participant’s response with his level of agreement with each view allowed us to select a view for this respondent for the purposes of data analysis. More specifically, statement 4 was unclear in that it may hint at an *RTS* view (in the sense that science has failed to teach us to be better human beings) or a *contrast* view (in the sense that it is not the responsibility of science to teach people how to be better). Cross-checking showed that this student agreed with a *contrast* view whereas he

disagreed with *RTS*¹⁰. Similar patterns were found for other samples (data not shown).

A larger number of participants chose to provide additional information among the Pakistani sample (14 students). However, although 11 provided extra descriptions in response to item H, all of these selected one of the views provided as their preferred view in question 2. Their information is consistent with their selected view in all cases except for one respondent who did not clearly introduce a new view but simply elaborated on the view selected. In addition, there were 3 students who wrote extra information but did not select a preferred view. The three written descriptions were not clear enough to determine whether these represented new views. Therefore, I allocated these respondents to the “Other Response” category together with another two students who neither chose a view that best described their personal views (item 2) nor provided an alternative view (item H) (see Table 4.4). Overall, the number of additional statements and their consistency with existing views from these studies strongly suggests that the range of views used in the research tool is sufficiently inclusive and that additional views are not required to capture the views of the large majority of these students.

Another form of validation applicable to the *SRSII* was the determination of the degree to which the data obtained correspond with predictions made *a priori* based on characteristics of selected subsamples. Cobern (2000) discusses historical shifts in western interpretations of the relationship between science and religion and how the two have affected contemporary views in society. Respondents with different cultural heritage are likely to show different distributions of views, informed both by contemporary philosophical positions and their ancestry. Among participants in the Thai sample, of whom approximately two thirds were Buddhists and the remainder were Christian, response data were consistent with most of the predicted differences between

¹⁰ Given the level of agreement, although I have found this analysis helpful in verifying the validity of the tool, it may be more appropriate in future surveys to exclude any respondents who provide an alternative mode, unless it is obvious that additional modes have emerged.

Buddhists and Christians. For example, among those accepting statements consistent with an *incompatible* view, the number of *Compartmental* students of the two religious traditions appears to be fairly similar (about 12%), which is consistent with the idea that this view represents those who have not considered the problem in depth, rather than being religion-dependent (data not shown). Next, all of the *RTS* students ($n = 11$) were Christians and 95.7% of the *STR* holders ($n = 27$) were Buddhists, as might be expected from the different emphases on the role of science and enquiry within these religious traditions.

Among those holding *compatible* views, although over 30% of both Buddhists and Christians chose *Complementary*, different proportions of holders of the *contrast* views (*Different Questions* and *Different Methods* combined) and *Coalescence* views were found among the two religious groups. The ratio of the response categories *contrast* to *Coalescence* among the Buddhist sample is 3:1, compared to 1:1 among the Christians. These ratios indicate that Buddhist students more commonly choose to separate science from religion and that Christian students appeared to wish to combine religious schools of thought with scientific knowledge. This greater tendency of Buddhists to separate scientific and religious frameworks is consistent with the view of Cioccolanti (2007). In addition, the proportion of respondents selecting a *Coalescence* view was considerably higher among the Thai sample than the Scottish one, consistent with Alexander's (2007) prediction that Eastern societies should demonstrate a greater tendency towards *Coalescence*. Interestingly, however, these findings suggest that this difference is not due to religious beliefs alone because it emerged even among the Christian students in the Thai sample. Finally, among the Pakistani sample, over 80% of respondents selected either *RTS* or *Complementary* views, suggesting a stronger emphasis on traditional religious teachings among this sample.

4.8 Considerations for Future Studies

Given that the *Compartmental* view is adopted by a fairly large number of the students in the Thai study, I wondered whether there might be different ways in

which individuals compartmentalise science and religion as is the case for *conflict* and *contrast* views. For example, there might be those who compartmentalise science and religion because they are unable to resolve or “understand” the conflicts, while others compartmentalise because they are unable to commit or “decide” which should take priority. In my interview study (Yasri and Mancy, 2012), the student who was categorised as *Compartment* claimed to be unable to commit precisely *because* she did not understand the situation sufficiently well, and the two may well be related. In this study, individuals who believed that they did understand the conflicts but were nonetheless unable to decide between science and religion might have been expected to explain this in the space provided; however, no student did so.

I also wonder whether individuals might find it difficult to select a position if they believed that science should take priority on some issues and religion on others. I suspected that students would be more likely to see discrepancies between science and religion in some specific contexts (e.g. evolution) than in general. However, it is unclear whether learners are aware of a sufficient number of such cases to allow them to consider that science/religion takes priority on “some issues” (in the plural), thus warranting the addition of a new view. Furthermore, even if they are aware of a significant number of issues where both science and religion make claims to knowledge, whether their choice about which to prioritise differs between these is currently unknown. I also wonder whether such a view, if offered, would be “too easy to choose” as a preferred view by non-committal respondents, and therefore fail to allow us to detect the differences among views.

Furthermore, I predicted that students who felt a strong need to provide a response of the type that science takes priority for some issues and religion for others, would have selected “agree” or “strongly agree” with both *RTS* and *STR* views. The Thai sample was used to validate this assumption. Among the 10 students who did show this pattern of responses to *RTS* and *STR*, two appeared not to have engaged with the question (selecting the same agreement category for all views), and among the remaining eight, 5 selected *Complementary* as their preferred view. It therefore seems likely that this alternative view is

relatively rare, or at least insufficiently clear to the respondents for them to be explicit about it. Rather than thinking of this as a subcategory of *Compartment*, I wonder whether learners holding this view might instead have selected the *Complementary* view, as this view makes no statement about how science and religion are combined, simply that both are useful: “Science and religion are complementary. Both are useful to understand all aspects of life”. In fact, given that the *Complementary* view was endorsed by a large proportion of responses in all samples, it seems likely that future work to better understand this view would be productive.

4.9 Conclusion

I conclude that despite its simplicity, the *SRSII* is sufficiently sophisticated to elicit respondents’ views on the relationship between science and religion and to provide reliable information about the degree of agreement with each of these views. Table 4.4 shows that the questionnaire was valid and robust enough to elicit the required information from the vast majority of participants without difficulty. The language was straightforward enough to allow participants to answer the questions, and almost all of the participants were able to select a preferred statement representing their personal view from the variety of viewpoints of relating science and religion. It is noteworthy that this was the case in Buddhist, Christian and Muslim religious contexts, supporting the idea that the *SRSII* is appropriate for use in a range of religious settings and geographical regions.

Although my colleagues and I have tested the *SRSII* in three diverse geographical locations and religious contexts, as well as with high school and undergraduate samples, further testing would be advantageous. Firstly, it would be instructive to gauge the response of trained philosophers and theologians to the questionnaire. It would also be informative to test its use with other religious groups and a group consisting primarily of those without any religious affiliation, as well as with a general public sample and younger school students. Moreover, replicating the existing studies reported here would lead to better understanding of whether these findings can be generalised. It would also be

interesting to see how the inventory can inform our understanding regarding changes over time in perceptions of the relationship between science and religion in the form of a longitudinal study. The tool could also be used with the general public perhaps in conjunction with studies on scientific issues of public or policy concern, as well as with practicing teachers, perhaps in the context of a study relating their personal viewpoint and their teaching approach or their response to the views held by their students.

Use of the tool may also help researchers to identify further questions of interest. It would be interesting to see whether the *SRSII* items could be used as fruitful stimuli in interview studies and if the underlying classification scheme on which it is built (Figure 4.2) could provide a useful rubric for analysing interview data. Finally, other uses of the instrument could be explored. For example, it would be valuable to consider whether the instrument could be adapted for use as a tool in science or religious education classrooms in order to elicit discussion on the natures of science and religion as knowledge-generating enterprises.

I suggest that both science and religious education teachers would gain direct benefit from using this tool in their own settings. As suggested by Yasri and Mancy (2012), knowing how students perceive the relationship between science and religion should help teachers select appropriate learning materials and understand student learning processes, especially in the context of evolution education. Specifically, students holding compatible views are likely to experience less conflicted learning about evolution; however, they are expected to require different kinds of support. For example, those holding a *contrast* view may benefit from support in which differences between scientific and religious domains are explicitly highlighted, those taking the *Coalescence* view would benefit from teaching that helps them understand the intersection between religious and scientific understandings in the light of the interpretation of scientific knowledge through the lens of religious understandings, and those taking the *Complementary* view may benefit from teaching that allows them to explore connections between scientific enquiry and religious implications. In contrast, those taking incompatible views are more likely to experience tensions

when learning about evolution. Yasri and Mancy (2012) suggest that their perception of incompatibility is likely to persist because without support, these individuals are unlikely to see ways to resolve the conflict, and they may reject evolution for apparently religious reasons, especially if they are unaware of other views of the relationship between science and religion. Therefore support for these learners needs to be provided in a form that helps them to construct their understanding of the natures of science and religion, potentially through discussion of the *SRSII* that can be used to make them aware of alternative views, including compatible views. I believe that addressing the relationship between science and religion before dealing with evolution-creation controversies is likely to be a more productive strategy than the converse because it is likely to feel less threatening to students to address the relationship without reference to particular controversial topics initially. This approach may therefore make later discussions of evolution less controversial because students will have already been exposed to a range of reconciliatory possibilities. However, instruction must also respect personal beliefs and avoid leading students to take one particular view.

Other approaches might include using the *SRSII* to develop vignettes of different views in order to generate classroom discussion or debate. Alternatively, learners may be asked to identify the view of various thinkers and critics (e.g. based on extracts from writings by or interviews with Richard Dawkins, John Lennox, Stephen Jay Gould, etc.). These approaches may be less intimidating for use in classrooms where there is known to be considerable divergence of opinion. Learners may also be asked to write reaction or discussion papers on the basis of vignettes or autobiographic readings.

In addition, this inventory can be used to initiate in-depth discussions regarding how students would provide reasons for their adopted view and/or for not adopting others in the light of how they view religion, science, and their respective claims. For example, Gauch (2009) distinguishes between necessary and unnecessary presuppositions of science, identifying the former as the two presuppositions that (1) the universe is orderly and (2) the universe is comprehensible. The understanding of the necessary and unnecessary

presuppositions of science is an important part of Nature of Science, and thus of scientific literacy. Although the tool does not directly address the distinction between these, some inferences could be drawn from student responses. For example, learners who select a *contrast* view may consider that science has no role in answering worldview questions. Discussions initiated by the tool might bring to light the presuppositions adopted by students, helping teachers to explicitly address which presuppositions are unnecessary and detrimental to scientific thinking (Cobern, 2000, Gauch, 2009). Alternatively, the tool could be used in conjunction with one of the Nature of Science frameworks in the literature (Cho et al., 2011, Lederman et al., 2002).

I believe that perceptions of conflict between science and religion could be minimised by a better understanding of the origin of conflict through highlighting presuppositions by this use of the *SRSII*. Doing so should facilitate the design of more supportive classroom environments and foster learning that minimises emotional challenges. In addition, students introduced to the *SRSII* directly would themselves be able to learn about the different views concerning the relationship between science and religion held by other people. This might be an effective way to approach the concerns raised by Billingsley et al. (2012), Winslow et al. (2011) and others that school students might not be aware of the existence of other views, especially the compatible views. Testing these suggestions is needed.

4.10 Summary

The importance of this work lies primarily in the synthesis of the range of viewpoints about the relationship between science and religion expressed in the philosophical literature, resulting in a categorisation scheme that clearly demonstrates the relationships between these taxonomies. This scheme provided the framework for the second contribution of this work, namely the development of the *SRSII*, a short survey that can be used to identify respondent views of this relationship. The *SRSII* characterises respondents as preferring one of the several ways of relating science and religion identified in the synthesis of taxonomies. Being able to easily characterise each learner's preferred views

should be valuable to educational researchers as should allowing learners to self-identify and learn about alternative views. Educators could also benefit from knowing the baseline distribution of views within a given student population. Use of the instrument and the literature review underpinning its development will also facilitate comparisons between existing and future studies.

Chapter 5

Student acceptance of biological evolution

Student acceptance of evolution is one of the key research areas in evolution education. This may be due to the fact that it has been found to relate to both student understanding of the theory of evolution (at least in some studies) as well as the nature of science. However, classifications of student levels of acceptance of evolution remain problematic. Many authors classify students in a rather radical manner into two main groups - acceptors and rejecters. In addition, although student reasons for accepting or rejecting evolution have been studied in other studies, student justifications for levels of acceptance have not been explored using the framework of cognitive authority. This second empirical chapter therefore investigates student acceptance of biological evolution and justifications for levels of acceptance. Five qualitatively different levels of acceptance of evolution are used in this study, consisting of *strongly accept*, *accept with reservation*, *being unsure*, *reject some parts* and *strongly reject*. The study shows that students tend to hold the intermediate levels of acceptance rather than the two extreme levels. Their justifications for their level of acceptance tend to be associated with science and religion as a cognitive authority. Those accepting evolution tended to rely on science as a cognitive authority or justified their viewpoint through the refusal of religion as a cognitive authority; whereas, those with reservations, unsure or rejecting evolution tended to rely on religion as a cognitive authority or justified their viewpoint through the refusal of science as a cognitive authority. In addition, the study shows that a key element of student justifications that is central to student understandings is the nature of science. Those having a sound understanding of the nature of science demonstrate their acceptance of evolution; while those holding a knowledge that might be called a “pseudo” nature of science, tend not to accept evolution.

The chapter begins with a review of the importance of student acceptance of evolution and previous empirical studies which examine different levels of student acceptance of evolution, followed by a review of research investigating rationales used to justify acceptance or non-acceptance of evolution. In the following section, I apply the framework of cognitive authority to group together factors influencing student rationalisations according to the forms of cognitive authority that underpin these. The review points to the importance of this empirical study by forming two specific research questions and the rationale behind the development of the research instrument. Then data collection and data analysis are presented, followed by findings, discussion and conclusion.

5.1 Acceptance of evolution

Student acceptance of evolution is an important research topic in evolution education for a number of reasons. First, it is found to be positively associated with student development of scientific understandings such as understandings of the content of evolutionary theory measured in the form of final grades (Ingram and Nelson, 2006), as well as understanding of the nature of science (Lombrozo, Thanukos and Weisberg, 2008), in large-scale studies. However, the association between student acceptance and understanding of evolution is less clear-cut in some other qualitative studies such as Demastes-Southerland, Settlage, and Good, (1995), perhaps because of the nature of qualitative research which is able to uncover variations of responses. Second, lack of acceptance of evolution may contribute to negative learning experiences about evolution. For example, McKeachie, Lin and Strayer (2002) show that students who did not accept evolution in their survey study expressed lower intrinsic motivation, less interest, higher anxiety and more emphasis on grades when learning about evolution. In other studies, students who did not accept evolution chose not to engage with the learning at all (Meadows, Doster and Jackson, 2000) or learned in order to falsify it (Yasri and Mancy, 2012).

Besides these educational implications, Brem et al. (2003) discuss the influence of student acceptance of evolution on personal and societal implications as they report that their US college student participants viewed undesirable

consequences of accepting evolution, consisting of increase in selfishness and racism, and decrease in the sense of spirituality, purpose of life and self-determination. Therefore, these studies together suggest that it is important to study student acceptance of evolution in order to help students develop their understandings of evolutionary theory as well as the nature of science. In addition, it is also important to study student justifications for accepting or not accepting evolution in order that teachers and educators would be able to assist their students to view the consequences of accepting evolution in more positive ways, as well as helping them to learn evolution with minimal tension.

One crucial aspect of the research topic on student acceptance of evolution that I would like to review here is concerned with the construct of the term *acceptance* used by researchers, in order to be explicit to which construct I refer in this thesis. At a philosophical level, researchers have attempted to draw a clear distinction between *acceptance* of evolution and *belief* in evolution. For example, Smith and Scharmann (1999) explain that *acceptance of evolution* implies the justification of the validity of the theory of evolution based on a systematic evaluation of evolutionary evidence; whereas, *belief* in evolution implies subjective judgements based on personal perspectives.

At an empirical level, Donnelly et al. (2009) note that acceptance of evolution encompasses a range of ideas including accepting evolutionary evidence, accepting the status of evolution within the scientific community, accepting the explanatory power of evolution in biological sciences and accepting evolution in relation to religious beliefs. Along these lines, Smith (2010a) points out that different researchers apply different constructs of acceptance of evolution to their research measurements. For example, the construct of acceptance used by Ingram and Nelson (2006) is in the light of accepting evolution *as science*. Asghar et al (2007) apply it in the fashion of accepting evolution as *a scientifically factual phenomenon*. Furthermore, Rutledge and Warden (1999) define it in the sense of accepting evolution as *a scientifically valid explanation*. However, in this study, I adopt the construct defined by Smith (2010a, p. 525) which is in the line of “acceptance of evolution as the best current available scientific explanation of the origin of new species from pre-existing species”. This is due

to fact that the construct is commonly agreed by “a substantial proportion of evolution educators” (Smith, 2010a, p. 525). Therefore, in the following section, I will focus only on different levels of acceptance of evolution and methods used to classify levels of student acceptance.

5.2 Levels of student acceptance of evolution

A number of studies have investigated the extent to which school and university students accept the theory of evolution (as summarised in Table 5.1). According to the review of literature, there are at least four methods used in previous studies to measure and classify levels of student acceptance of evolution: quasi-continuous scales of acceptance using the Measure of Acceptance of the Theory of Evolution (MATE; Rutledge and Warden, 2000), binary categories used in quantitative studies such as Donnelly et al. (2009), Downie and Barron (2000), Southcott and Downie (2012) and Özay Köse (2010), ternary categories used in qualitative studies such as Hokayem and BouJaoude (2008) and Clores and Limjap (2006), and a category system based on the relationship between evolution and creation used by McKeachie et al. (2002).

Apart from MATE, the other quantitative studies present similar pre-defined categories of student acceptance of evolution, although they differ in research participants, settings, numbers of categories, category names, and research approaches for data collection. Donnelly et al. (2009), Downie and Barron (2000), Southcott and Downie (2012) and Özay Köse (2010) classify student acceptance of evolution based on binary options: those accepting evolution (often referred to as evolution acceptors or evolutionists) and those rejecting evolution (often referred to as evolution rejecters or creationists). An additional category is added in some other qualitative studies such as Hokayem and BouJaoude (2008) and Clores and Limjap (2006) to capture individuals who are unsure (or doubtful or uncertain) about evolution. In addition, McKeachie et al. (2002) examine student acceptance of evolution in the context where an explicit link between evolution and divine creation is made; thus some other additional options are proposed such as “both evolution and creation accepted” (McKeachie et al., 2002).

On the one hand, these categories can be understood as qualitatively distinct categories (i.e. accept, unsure or reject evolution). On the other hand, they can be viewed as levels¹¹ of acceptance in which those who are unsure about the acceptability of evolution may sit somewhere between those accepting evolution and those rejecting it. The latter perspective suggests that there might be other levels in the “continuum”. For example, Smith (2010a) suggests the additional levels “acceptance with some reservations” or “reject some parts”. Existing studies are discussed in more detail in the next sections according to the number of categories used.

5.2.1 Quasi-continuous scales of student acceptance of evolution

The MATE is a 20-item evolution acceptance questionnaire based on a 5 Likert-scale method which is most widely used in evolution education research (Smith, 2010a). Rutledge and Warden report a very high value of a reliability coefficient of 0.98 for MATE. The 20 items measure five different aspects related to acceptance of the theory of evolution: the scientific validity of the theory of evolution, the acceptance of the theory of evolution within the scientific community, creationist perspectives on divine creation, human evolution and the age of the earth (Rutledge and Warden, 2000). Student acceptance is then scored from 20-100 possible points, with 20 being the lowest level of acceptance and 100 being the highest level of acceptance. The corresponding scores and categories for acceptance are 89-100, Very High Acceptance; 77-88, High Acceptance; 65-76 Moderate Acceptance; 53-64, Low Acceptance; and 20-52, Very Low Acceptance (Rutledge, 1996).

However, MATE is not considered as the best tool for assessing student levels of acceptance focused in this study because of a number of reasons. First, although the framework for classifying the five continuous levels of acceptance of evolution based on the corresponding scores seems to be reasonable, it fails to offer a clear boundary between those accepting evolution and those rejecting

¹¹ It should be noted that although I employ the word “levels” in this chapter, rather than viewing levels as ordinal (in the statistical sense), they are treated as categorical (i.e. qualitatively different).

evolution, even though the labels “low” and “very low” acceptance may hint at the tendency of rejection of evolution. This critique is supported by the actual use of the MATE by Donnelly et al. (2009). Although they used the MATE as a tool to classify their students as “evolution acceptors” and “evolution rejecters”, they did not rely on the suggested framework of the five continuous levels, but adopted statistical software to convert the Likert rating scale data to interval data and designed the breaking point to distinguish the two groups of students by themselves. This statistical complication not only discourages basic users of statistics, but it also suggests that the classification into two groups is done in an arbitrary manner (i.e. depending on the breaking point decided by the researchers). Furthermore, the suggested approach does not weight items; however, there is no guarantee that all items provide the same amount of information in relation to the construct of interest, that is, acceptance.

Similarly, although Hokayem and BouJaoude (2008) also used the MATE, they did not classify levels of student acceptance of evolution based on this tool. In fact, they explained, “this questionnaire [MATE] was just used to gather preliminary information to initiate a discussion about the topic [the theory of evolution] and illustrate any changes in mind later on” (p. 401). They actually classified student levels acceptance based on interviews. It is true that the MATE has been widely used in educational research, but not in the way that it was originally intended.

The second reason is provided by Smith (2010a). From a philosophical perspective, Smith (2010a) critiques the MATE for conflating knowledge with acceptance. From an empirical perspective, although the MATE has been shown to have a high Cronbach alpha coefficient value, suggesting that the items measure a single factor, Smith (2010a) questions whether that factor is really acceptance as he points out: “what does it mean, for example, when a respondent asserts (“agree”, “strongly agree”, etc.) to the following statement: “Evolutionary theory generates testable predictions with respect to the characteristics of life”? Does the respondent accept the statement as true? Does s/he believe the statement is true? Does s/he accept/believe the statement as valid?” To address this issue, Smith (2010a) suggests a possible way to measure

acceptance of evolution as well as the classification of levels of acceptance of evolution in a way that is less ambiguous with respect to the distinctions between belief and acceptance, which will be discussed later.

Authors	Sample/context	Research method	Categorical levels of acceptance of evolutionary theory
Donnelly et al. (2009)	29 high school students in USA	Mixed methods including MATE	1. Acceptors (37.9%) 2. Rejecters (62.1%)
Downie & Barron (2000)	2584 undergraduates in the UK	Questionnaire	1. Acceptors (no data provided) 2. Rejecters (6.7%)
Southcott & Downie (2012)	1403 undergraduates in the UK	Questionnaire	1. Acceptors (no data provided) 2. Rejecters (5.0%)
Özay Köse (2010)	250 high school students in Turkey	Questionnaire (using Downie & Barron's tool)	1. Acceptors (26.8%) 2. Rejecters (73.2%)
Hokayem & BouJaoude (2008)	11 undergraduates in Lebanon	Interviews using MATE questions	1. Accepting evolution (63.6%) 2. Uncertain about evolution (27.3%) 3. Rejecting evolution (9.1%)
Clores & Limjap (2006)	37 undergraduates in the Philippines	Interviews and journal entries	1. Acceptance of evolution (62.16%) 2. Doubtful about evolution (13.51%) 3. Rejection of evolution (24.32%)
McKeachie et al. (2002) - Pre test	60 undergraduates in USA	Questionnaire	1. Evolution accepted (18.3%) 2. Unsure (36.7%) 3. Evolution-Creation accepted (28.3%) 4. Evolution rejected (16.7%)
McKeachie et al. (2002) - Post test	28 undergraduates in USA	Questionnaire	1. Evolution accepted (10.7%) 2. Unsure (10.7%) 3. Evolution-Creation accepted (28.6%) 4. Evolution rejected (50.0%)

Table 5.1: Summary of previous studies on categories of acceptance of evolution

Finally, I think that the most honest and the simplest way to investigate student acceptance of evolution is to ask them directly whether they accept it or not. In the context of this survey study, this can be done in two main ways: one is to provide a range of pre-defined categories for them to choose based on a questionnaire; the other is to provide an open-ended question for them to

complete. The next sections will present categorical levels of student acceptance of evolution using either pre-defined categories or categories emerging from an inductive approach based on interviews.

5.2.2 Binary categories of student acceptance of evolution

A number of quantitative studies present the classification of levels of student acceptance into two: those accepting evolution or “acceptors” and those rejecting evolution or “rejecters”. Using the MATE alongside additional analyses, Donnelly et al. (2009) classified 29 US high school biology students into 2 groups: 11 *acceptors* and 18 *rejecters*. All of the acceptors accepted human evolution as well as evolution as the explanation for modern life forms, and none accepted young-earth creationist statements. In contrast, among the rejecters, 12 accepted the statement that evolution is wrong because it contradicts the Bible and seven accepted the statement for young-earth creationism. Although the sample is small, and generalisations are therefore problematic, the ratio between acceptors and rejecters in this study does nonetheless reflect on the ratio reported in a larger survey study based on 1484 American adults which is almost 1:1 (Miller et al., 2006).

A similar categorisation scheme is found in the studies of Downie and Barron (2000) and Southcott and Downie (2012). These two studies surveyed how undergraduate biology students attending a Scottish university perceived the theory of evolution and what reasons made them accept or reject it. The former study was conducted during 1987 and 1999 with 2854 participants. The latter was carried out during 2008 and 2010 with 1403 participants. The student participants are classified to be either *acceptors* or *rejecters* depending on whether they accept that “some kind of biological evolution, lasting many millions of years, has occurred on earth” (Downie and Barron, 2000, p. 140). Interestingly, unlike Donnelly et al. (2009)’s US based study, it is found that, within this context, the proportions of rejecters in both studies are much lower than the acceptors. In the former study, the average figure of the rejecters is 6.7%, whereas the figure in the latter work is about 5.0%. In contrast, using the research tool of Downie and Barron (2000) in a different context, Özay Köse (2010) showed that among 250 Turkish secondary school students, 73.2% were

categorised as *rejecters* on the basis of their responses; whereas 26.8% were categorised as *acceptors*. These differences are probably explained by differences in the cultural context, as well as sample characteristics (e.g. Downie and Barron's samples had chosen to study biology).

Like the MATE, this binary categorisation scheme is not used in this study. This is due to the fact that although the use of two oppositional categories (i.e. *rejecters* versus *acceptors*) is predominant in research studies as well as in the public domain (Alexander 2009), it is not accepted by a number of scholars. For example, Reich (2010) argues that these categories rely on binary logic that fails to reflect the inter-woven and complex nature of knowledge systems such as those of science and religion. He also argues for a developmental sequence of positions of "epistemic cognition", according to which learners gradually become more competent at relating different ideas in religion and science. Therefore, it is reasonable to argue that these two radical categories fail to represent actual levels of acceptance of evolution, and this points to the importance of the development of a research measurement tool that includes a wider range of levels of acceptance of evolution and is explicit to the specific aspect of evolution that is being measured.

5.2.3 Ternary categories of student acceptance of evolution

Rather than categorising student acceptance of evolution into two oppositional groups, a number of studies, especially those by authors adopting a qualitative approach, provide an optional level for those who are unsure or undecided about the whether or not they accept evolution. For example, Hokayem and BouJaoude (2008) examine student perceptions of the theory of evolution with regard to their epistemological beliefs about science and religion, focusing on 11 biology students who attended a course on evolution at university level in Lebanon, holding either Christian or Muslim beliefs. Using mixed research methods relying on semi-structured interviews initiated by MATE questions, the researchers classified their student participants into 3 groups: seven who *completely accepted*, three who were *unsure*, and one who *rejected the theory*.

A similar categorisation is presented by Clores and Limjap (2006) who used a qualitative study to examine how university students in the Philippines perceived the theory of evolution. The study involved 20 biology and 17 psychology students of Roman Catholic faith undertaking a 4-week general biology course, who voluntarily took part in this study. Based on interviews and written tasks after completing the course, the researchers present three categories of student acceptance. These comprised 23 students who *accepted*, nine who *rejected* and five who were *unsure* about whether they accepted the theory of evolution.

Apart from providing rich information regarding student opinions on acceptance of evolution, these qualitative and mixed-methods studies suggest that there are a number of students who are unable to make a decision about whether they should accept evolution or not. This strengthens the critique about the drawback of the binary logic and, of course, these students should not and cannot be labelled as either *acceptors* or *rejecters*. The qualitative nature of these studies thus makes it valuable to examine the proportion of participants who are unsure about evolution compared to those who accept and reject evolution in a larger group of sample using a new research instrument which includes this categorical level.

Nonetheless, researchers need to be careful when including a “neutral” or “unsure” option in a questionnaire. As suggested by Kulas et al. (2008), in quantitative work adopting a five or seven Likert-type statements, this “middle response” (i.e. unsure) may be selected for different reasons. For example, it may be an indication of uncertainty (i.e. no firm decision has been made), neutrality (i.e. genuinely having no partiality), or ambivalence (i.e. neither agree nor disagree), the non-applicability of other response categories (i.e. none of the categories capture the participant’s view), in addition to possibly the worst case in which a participant selects the option because he or she does not want to consider the statement in any depth or does not really understand what they mean. This “worst case” scenario is less likely to occur in qualitative interview studies because it is possible for researchers to ask participants further questions to clarify what is unclear. For example, those students who

were classified in this category in Hokayem and BouJaoude (2008) and Clores and Limjap (2006) were able to explain *why* they were uncertain about evolution. Usually in questionnaire-based studies it is unclear what it means when the “unsure” option is selected. In a questionnaire, it is therefore valuable to ask participants directly why this box is ticked. However, the combination of two tasks - a selection of a level of acceptance of evolution based on a Likert item and a written explanation concerning reasons for selecting such level - should allow researchers to gain information regarding different levels of student acceptance of evolution and reasons for making a particular level of acceptance, while avoiding some of the ambiguities surrounding the selection of the “unsure” option in the absence of such information.

5.2.4 Multi-dimensional categories of student acceptance of evolution

In the situation where any alternatives explanations of the origins of life and biodiversity are known - for example in a Christian context - an alternative approach has been used that directly integrates these alternatives, leading to a multi-dimensional scheme for classifying qualitative different categories of student acceptance of evolution. McKeachie et al. (2002) explored acceptance of evolutionary theory by American college students taking a biology course using a questionnaire administered twice during the term (the first and the last weeks). Based on a single question with four qualitatively different choices representing different opinions on the acceptance of evolution in relation to interpretations of the biblical account of divine creation, the researchers report that among 60 volunteering participants at the start of the study, there were 11 who *accepted evolution as fact*, 22 were *unsure* about evolutionary theory, 17 *accepted both* the theory of evolution and the biblical account of divine creation, and 10 *rejected evolution*. However, by the end of the study when the second data collection was conducted, some of these perceptions had changed in the direction of greater acceptance of evolution over the period of the study. Although they did not collect evidence on causes, the researchers believe that these changes were the consequence of students' intrinsic motivation to learn about evolution related to their acknowledgement of the importance of the theory of evolution in the scientific community. Nonetheless, among those

students who claimed to accept both evolution and divine creation, it remains unclear in what particular ways they reconciled the two accounts.

An important question is the relative usefulness of this kind of categorisation compared with those that do not make explicit reference to alternative explanations. Indeed, different research studies have different purposes. Specifically, student acceptance of evolution within the context of religious beliefs might be of interest of many researchers. However, some learners might not use religious lenses when considering the theory of evolution, and might use other rationalisations for accepting or rejecting evolution, or might provide justifications that rely on other forms of reasoning, whether or not their acceptance or rejection is religiously motivated. For example, the only student who rejected evolution in the study of Hokayem and BouJaoude (2008) did not express his opposition based on religious faith but on his scepticism about evolutionary evidence. The same is true with participants of Clores and Limjap (2006) who appeared to reject evolution based on their misconceptions about evolutionary theory and the nature of science. In addition, in a context where the theistic beliefs regarding divine creation is little known, the inclusion of a specifically religious additional position (both evolution and creation accepted) might be awkward and rather less general. It is therefore useful to gain insight into how students perceive the theory of evolution on its own merits, only later focusing more specifically on its relationship with other explanations. In other words, rather than limiting student acceptance of evolution in religious contexts, the focus should be made on how students accept evolution as a scientifically valid explanation of the origin of life and emergence of the diversity of life forms. This allows religious rationales for particular levels of acceptance to emerge naturally. Claims about the roles of science and religion can be made more confidently if it is found that students still refer to religious perspectives even when the questionnaire question is explicitly limited to the scientific context.

5.2.5 The preferred categorical levels of acceptance of evolution

In this study, a preferred classification scheme for categorising levels of student acceptance is suggested by Smith (2010a). This scheme embraces the advantage

of the ternary classification scheme in terms of the inclusion of all possible ranges of levels of acceptance (i.e. acceptance, unsureness and rejection). In addition, it does not leave the usefulness multi-dimensional classification scheme which concerns qualitatively clear distinctions between categories. However, this study avoids drawing an explicit link between biological evolution and biblical creation as done in the study of McKeachie et al. (2002), but emphasises merely accepting evolution as a scientifically valid explanation of the biodiversity in order that participants would not be misled.

More specifically, Smith (2010a) suggests a more explicit way to classify the levels of acceptance of evolution than the approaches used in earlier studies. Similar to the idea of the ternary categories as discussed in 5.2.3, Smith (2010a) extends the levels of acceptance to five categories. In fact, these five levels of acceptance are typical in the 5-point Likert type of question (i.e. strongly agree, agree, unsure, reject, strongly reject). However, instead of dividing acceptance into *strongly accept* and *accept* as is usually done, Smith (2010a) divides it into *strongly accept* and *accept with reservation*. Likewise, instead of dividing rejection into *strongly reject* and *reject*, Smith (2010a) divides it into *strongly reject* and *reject some parts*. I consider that providing the categories in this way would enable participants to justify the qualitatively distinct space between *strongly accept* and *accept with reservation*, and between *strongly reject* and *reject some parts* more clearly. In addition, doing this would prompt respondents to think more carefully in terms of what the reservation is when they are going to select *accept with reservation* or what the rejected parts are when they are going to select *reject some parts*. On top of this, these minor modifications would help researchers ensure that respondents select one of these positions not because they only avoid choosing the “extreme” positions.

5.3 Justifications for levels of acceptance

In addition to assessing levels of acceptance, some of the previous studies also demonstrate different factors or reasons that influence student acceptance of the theory of evolution. These include understanding evolutionary evidence (Clores and Limjap, 2006; Downie and Barron, 2000), religious beliefs (Clores

and Limjap, 2006; Downie and Barron, 2000; Francis et al., 1990; Francis and Greer, 1999; Fulljames et al., 1991; Yasri and Mancy, 2012), and the status of evolutionary theory within the scientific community (Rutledge and Sadler, 2007). This section serves to elaborate these in greater detail. Two subsections are included composing findings from quantitative studies which adopt a survey approach using pre-defined reasons for accepting or rejecting evolution, and findings from qualitative studies using in-depth interviews in which reasons for accepting evolution are provided by students. Both advantages and disadvantages arising from these two types of studies are also highlighted, leading to the importance of the use of content analysis in this present study.

5.3.1 Justifications for acceptance based on pre-defined reasons

Some studies considering reasons for acceptance or rejection of evolution use pre-defined response categories. For example, on the basis of student selection of pre-defined questionnaire items providing reasons for or against accepting evolution, Downie and Barron (2000) suggest that there are three main reasons which contribute to student acceptance of evolution. These consist of the strength of evidence for evolution, the influence of teacher perspectives and unawareness of other possible explanations of the origins. The main reason taken by those who accepted evolution was the unavailability of other good alternative explanations that can explain the origins (selected by between 71% and 82% of the whole sample during the 12 years of the study). The main reason taken by those who rejected evolution was the adoption of the literal interpretation of the religious account of divine creation (selected by between 50% and 84% of the whole sample during the whole period the study). In addition, Downie and Barron (2000) show a comparable number of those accepting and rejecting evolution appear to make their justification based on evolutionary evidence. While 36% of those who accepted evolution considered that the evidence is “clear and unambiguous” (p. 142), 33% of those who rejected it claimed that it is “full of conflicts and contradictions” (p. 141).

Using the research tool constructed by Downie and Barron (2000), Özay Köse (2010) reports that 72.1% of Turkish high student participants rejected evolution on the basis of a literal interpretation of the religious account of divine creation.

In addition, 40.4% considered that the evidence for evolution is “full of conflicts and contradictions” (p. 192). In contrast to the Scottish sample, only 56.7% of those accepting evolution considered that there are no good alternatives to evolutionary theory; and 52.2% accepted the theory of evolution because of its “clear and unambiguous” evidence (p.192); furthermore, 44.7% accepted it because of the influence of science teachers and science textbooks (i.e. “I tend to accept what teachers and textbooks say: they show the evidence much better than I do” (p. 192)).

Recently, Southcott and Downie (2012) adopted a questionnaire-based survey to explore how first and final year bioscience students attending a Scottish University perceived the theory of evolution and what reasons were associated with their acceptance or rejection of evolution. The researchers show that almost half of the first year students (pooled sample of the two periods of data collection) who rejected evolution (N = 61) viewed that “there are alternative explanations for the diversity of life seen today (e.g. divine creation, intelligent design)”. About one fourth of them agreed that “there is insufficient evidence to prove conclusively to my satisfaction that evolution has occurred”, and one fifth agreed that “[they] have insufficient knowledge about evolution to show [them] that it has occurred” (p. 303). In contrast, they show that the pooled data (N = 859) showed that most of those accepting the statement for evolution (73.5%) agreed that evidence for evolution “is convincing and well supported”.

Turning to the final year students who were divided by the researchers into two groups: those having little experience on post-level 1 evolution courses (N = 218) and those having been exposed to a range of courses related to evolutionary theory (N = 255). The findings show that only 2.1% of the whole sample rejected the statement for evolution, all of whom came from those having little experience on post-level 1 evolution courses. In addition, like the first year students, most of the final year students (84.5%) accepted the theory of evolution because they find it “convincing and well supported” (p. 304).

In sum, these three studies point to a group of justifications for accepting or rejecting evolutionary theory which are related to both scientific and religious

perspectives. There are rationales associated with aspects of the nature of science such as the evidence for evolution and the creditability of evolutionary theory. Some students perceived evolutionary evidence as clear and convincing but others saw it as ambiguous and unconvincing. Some students accepted the creditability of evolutionary theory, but some preferred to adopt alternative explanations. In addition, there was evidence that some students employed rationales that were influenced by others such as science teachers' opinions or literal interpretations of biblical accounts on divine creation. However, no theoretical framework is subscribed to explain these justifications in the existing literature. Also, this range of rationales for accepting or rejecting evolution might not fully capture what students actually believe about evolution as they were pre-defined by the researchers. It is therefore important to review naturalistic accounts given by students themselves elicited by interview studies and these are presented below.

5.3.2 Justifications for acceptance in qualitative studies

Using the list of reasons proposed by Downie and Barron (2000) as a theoretical framework for data analysis, Hokayem and BouJaoude (2008) carried out in-depth interviews with 11 students in Lebanon. Their findings concerning student reasons for forming an opinion about evolution appear to be similar to those presented by Downie and Barron (2000), particularly in relation to the consideration of the evidence for evolution. Hokayem and BouJaoude (2008) report that "all students recognized the importance of concrete evidence" in making the justification whether evolutionary theory should be accepted. However, the researchers point out that the students differed in their perceptions of "the nature of evidence for the theory of evolution" (p. 402). Specifically, those accepting evolution perceived that the theory of evolution has been scientifically constructed through "concrete evidence". In contrast, those who were unsure and those who rejected evolution found the evidence unconvincing and speculative, rejecting evolution without referring to any religious reasons.

A wider range of reasons for forming an opinion on evolution is reported in the study of Clores and Limjap (2006) whose work adopts a more bottom-up

approach based on interviews and journal entries in a different educational context. More specifically, among those accepting evolution, two-thirds perceived that the theory of evolution is strongly supported by scientifically valid evidence which has been discovered in a cumulative manner by a large number of scientists. In addition, among them, many accepted evolution on the basis of a good understanding of the nature of science and scientific methods. However, the expression of the acceptance of evolution by some students appears to be associated with scientism (e.g. unconditional faith in the work and claims of scientists), as well as misconceptions about evolution (e.g. man evolved from monkeys).

Among those who were unsure or rejected evolution, in addition to their misconceptions about evolutionary theory (e.g. environmental determinism, divine revelation, evolution of plants and lower taxonomical animals only) and about evolutionary evidence (e.g. incomplete fossil records, missing links for speciation, pure imagination), they tended to deny evolution for religious reasons. Specifically, two students said that they were unsure about the correctness of evolution because there remain clashes between the scientific explanations of evolution and their creationist beliefs. Another student claimed that his creationist belief does not allow him to consider evolutionary theory as an account for the emergence of organisms. In addition, some of those who rejected evolution explained that evolution is less likely to occur based on statistical probabilities. Rather, they considered that the emergence of complex life forms points to design from God.

In sum, additional reasons for accepting and rejecting evolution are found in these qualitative studies ranging from perceived oppositions between the scientific and religious enterprises (e.g. scientism versus religious beliefs), understanding of the nature of science (e.g. interpretation of scientific evidence and the status of alternative explanations), to conceptual understanding (i.e. both accurate understanding of evolutionary concepts and misconceptions).

5.3.3 Summary of student justifications for acceptance of evolution

Based on the quantitative and the qualitative studies reviewed above, the list of reasons defined by the researchers or given by the students can be divided into two main clusters: reasons related to scientific perspectives (e.g. the evidence for evolution, the status of evolution within the scientific community, and the explanatory power of evolutionary theory) and reasons related to religious perspectives (e.g. literal interpretation of the scriptural texts and beliefs related to design in nature).

Of course, the influence of both scientific and religious perspectives on student acceptance of evolution is not a new topic. However, an emerging pattern of the student responses in relation to the two perspectives found in the previous studies is interesting and is not explicitly pointed out in the existing literature. The emerging pattern is that there are opposing ways of interpreting the same aspects: the evidence (it is clear and unambiguous vs it is conflicting and contradictory), accounts in the various kinds of “literature” (scientific vs bible), and the existence of good alternative explanations (as existing or not existing).

More specifically, for example, based on those students in Downie and Barron (2000) and Özay Köse (2010), it is evident that while there is a group of participants who prefer the reasons for accepting evolution (i.e. clear and unambiguous evidence, science teachers and textbooks say so, and no other good alternative explanations), there remains another group of participants who prefer the opposite statements for rejecting evolution (i.e. conflicting and contradicting evidence, scriptural texts do not say so, and there are good alternatives to evolution). Similarly, Clores and Limjap (2006) clearly define the same phenomena in two different aspects in their qualitative study. First, while there are those who accepted evolution based on scientific beliefs, there are those who rejected it for religious reasons. Second, while there are those who accept evolution because they perceive that it is well supported by evidence, those who reject evolution perceive that the evidence is incomplete and ambiguous.

The framework of worldviews, widely adopted by researchers in evolution education, may provide an explanation for this phenomenon. It explains that people give different meanings (e.g. accept or reject) to the same thing (e.g. evolutionary theory) because they hold different belief systems (e.g. scientific or religious or both) which have been cumulatively nurtured by their previous experiences and other people surrounding them (Cobern, 1989). Therefore, each individual is unlikely to see things as “they are” but as he or she is. In other words, individuals perceive and interpret evolution according to their worldviews which have been socially constructed by their own set of culture, faith and values. If the “end product” is the different levels of acceptance of evolution held by individual students, the “original input” should be student worldviews. However, how students process the “original input” to form the “end product” is unknown. In this study, I therefore wish to explore how students justify their levels of acceptance by using the framework of cognitive authority. The discussion of this framework is in the next section.

5.4 Cognitive authority

In the context of evolution education, Winslow et al. (2011) explain that student perceptions of the theory of evolution are typically influenced by a set of beliefs which students have been taught in their childhood from parents and/or church communities. When they reach school age, their perceptions are likely to be influenced by teachers, peers, as well as learning materials (Anderson, 2007, Clores and Limjap, 2006, Donnelly et al., 2009, Martin-Hansen, 2008, Taber et al., 2011, Winslow et al., 2011, Yasri and Mancy, 2012). These different sources of knowledge that individuals consider sufficiently reliable, trustworthy or compelling to influence their justification for accepting or rejecting evolution are cognitive authorities.

Rieh and Hilligoss (2008) explain the distinctions between two different forms of authority. One is *administrative authority* which is associated with the right to exercise power over others (i.e. those holding higher hierarchical positions or authoritative figures who can force decision making or make rules that others must follow). The other is *cognitive authority*, which is used to refer sources of

knowledge on which individuals rely when justifying their decision. In this study, I focus on the latter because the interest in this section is in the reasons that students consider sufficiently compelling when they decide to accept or not to accept evolutionary theory.

Wilson (1983), one of the key researchers in the area of cognitive authority, explains that people construct knowledge according to two different processes. One is through their personal encounters with entities of interest (direct experience). Knowledge gained through this direct experience or observation is called *first-hand knowledge*. In contrast, the other process of learning is through learning from others. This is important because a single individual cannot gain direct experience of all concepts; knowledge gained in this way is called *second-hand knowledge*. Wilson argues that we rely primarily on the latter process as much of our knowledge is gained from others.

While some students might be able to gain first-hand experience of evolution through conducting scientific research alongside scientists, normally school students have to rely on second-hand knowledge. In other words, students usually learn about evolution from science teachers and textbooks. Rasoamampianina (2012) explains that sources of second-hand knowledge can be found in many forms such as individuals (e.g. scientists, teachers, preachers and parents), texts (e.g. books, journal articles, conference proceedings and online materials), as well as institutions (e.g. the scientific community and research centres).

Applying a similar framework to evolution education, Smith (2013) points out two influential cognitive authorities¹² comprised of science and religion. However, he notes that the term authority does not refer to authoritative figures that can enforce decision making (i.e. top-down control) such as political influences of funding agencies on directions of scientific research or the absolute order of the Church to forbid certain explanations (as occurred in the

¹² Smith does not directly refer to ‘cognitive authority’ or to this framework explicitly, but the parallels appear clear.

past), that is administrative authority (Rieh and Hilligoss (2008). In contrast, he refers to the idea of cognitive authority as “real authority” (p. 607) which means any figures or sources that one refers to as the basis of rationales for making one’s own decision or judgement on a particular situation (i.e. according to a bottom-up process).

Focusing first on science as cognitive authority, Smith (2013, p. 611) explains that “learners stand at the end of chain of evidence - at the end of a justificatory chain of testimony that begins with the researchers who actually made the observations or conducted the experiments that produced the evidence”. This means that those relying on science as a cognitive authority justify their thoughts and beliefs through forms of evidence provided by original researchers who conduct experiments or observations which are generally presented in textual forms such as books, reports research articles and weblogs, as well as verbal presentations such as lectures and seminars.

Turning to religion as a cognitive authority, Smith (2013) explains that individuals rely on religion in “four interlocking forms” consisting of perceived doctrines of God, sacred texts, church traditions and church people. He points out that the hearers or readers of the sacred texts (i.e. those relying on religion as a cognitive authority) are influenced by the interpreters (e.g. bible teachers, preachers, and church leaders) who interpret the sacred texts according to the denominational tradition of the church which hold certain doctrines of God. The next two subsections explain both scientific and religious authority in greater detail.

5.4.1 Science as a cognitive authority

As Wilson (1983) argues, learners are likely to rely on second-hand knowledge about evolution. According to Wiles (2010), the flow of knowledge about evolution comes from scientists (individuals) who conduct experiments and observations and contribute to a solid body of scientific knowledge within the scientific community (a form of institution), and then this body of knowledge is transferred to learners through science education (instruction). I therefore specifically focus on the end of this sequence as it relates to scientific

knowledge passed on to students (originally from individual scientists and science education institutions) via school science instruction.

Aspects of NOS	Descriptions
<i>Empirical</i>	Scientific claims are derived from, and/or consistent with, observations of natural phenomena, and eventually adjudicated by reference to these observations.
<i>Inferential</i>	Most scientific constructs are inferential in the sense that they can only be accessed and/or measured through their manifestations or effects.
<i>Creative</i>	Generating scientific knowledge involves human creativity in the sense of scientists inventing experiments, and theoretical models.
<i>Theory-laden</i>	Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training and expectations influence their work
<i>Tentative</i>	Scientific knowledge is reliable and durable, but never absolute or certain.
<i>Scientific methods</i>	There is no single "Scientific Method" applied for all but scientists observe, compare, measure, test, speculate, hypothesise, debate, create ideas and conceptual tools, and construct theories and explanations.
<i>Scientific theories</i>	Scientific theories are well-established, highly substantiated, internally consistent system of explanations for phenomena.
<i>Scientific laws</i>	Scientific laws are descriptive statements of relationships among observable phenomena which are not hierarchically superior than theories as commonly believed
<i>Social dimension</i>	Scientific knowledge is socially negotiated, referring to the constructive values for communication and criticism within the scientific enterprise, which serve to enhance its objectivity.
<i>Cultural embeddedness</i>	Science is a human enterprise embedded and practised in the context of a larger cultural milieu, including worldviews, religions philosophies and so on.

Table 5.2: Aspects of the nature of science with descriptions, originally contributed by Abd-El-Khalick (2012, p.356-357)

The theory of evolution as generally presented in biology textbooks contains two main elements: (1) scientific explanations of the theory of evolution regarding mechanisms involved in evolutionary processes such as natural selection and genetic variation, and (2) forms of evidence for evolution such as fossil records,

comparative anatomy and molecular biology based on DNA similarities (Stearns and Hoekstra, 2005). However, in addition to these elements, science educators also promote the instruction of the nature of science (Abd-El-Khalick, 2012, Biological Sciences Curriculum Study, 2005, Cho et al., 2011, Dagher and BouJaoude, 2005, Lombrozo et al., 2008, Rutledge and Warden, 2000). In fact, understanding of the scientific explanations of the theory of evolution as well as forms of evidence for evolution begins with the nature of science (Biological Sciences Curriculum Study, 2005). This therefore leads to the inclusion of the nature of science in this section. The rationale is that once the nature of science is taught to students in the light of how science works and how it is different from non-science and pseudo-science, and how a scientific theory is developed from evidence obtained from experiments and observation, then it would become a form or forms of cognitive authority influencing student perceptions of the acceptance of evolutionary theory.

While greater detail on these aspects of the nature of science can be found in a number of research articles such as Abd-El-Khalick (2012) as summarised in Table 5.2 and Scott (2005), this chapter focuses on ways in which students use or misuse these aspects of the nature of science as a cognitive authority when justifying their acceptance of evolution. Interestingly, using semi-structured interviews with 15 university biology majors in Lebanon, Dagher and Boujaoude (2005) point out that students perceive the nature of science in the context of evolution rather differently from how scientists generally do. For example, relying on *empirical* aspects, some of them considered that evidence for evolution has to be completely proven. Relating to *tentative*, some viewed that evolutionary theory is uncertain and changing all the time. Associating with *inferential*, they thought that no direct experiments particularly related to macroevolution can be conducted. Based on *scientific methods*, they claimed that the development of evolutionary theory misses one or more steps of scientific methods. Furthermore, relying on perhaps both *scientific theories* and *scientific laws*, some of them argued that evolutionary theory cannot predict the course of evolution. Although Dagher and BouJaoude (2005) do not use the framework of cognitive authority, their findings can be re-interpreted in light of this. The study points out that the students justified their acceptance of

evolution by relying on science as a cognitive authority through aspects of the nature of science. However, their understanding of the nature of evidence is insufficiently sophisticated.

5.4.2 Religion as a cognitive authority

As discussed in many studies, not only does science play a role in evolution education, so too does religion. Now the review focuses on religion as a cognitive authority when students justify their level of acceptance of evolution. In his review of research studies investigating factors influencing acceptance of evolution, Smith (2010a) concludes that religious beliefs, and especially fundamentalism, are negatively related to acceptance of evolution, while Mazur (2004) shows they are also the strongest predictor of rejection of evolutionary theory among the US public. It is also possible that the psychological constraints that hinder evolutionary understanding are related to religiosity, especially since many religions, including most branches of Christianity, implicitly or explicitly espouse a worldview.

While these studies demonstrate an important role for religious beliefs in student rejection of evolutionary theory, this is even clearer in Yasri and Mancy (2012)'s study which shows that students relied on second-hand knowledge associated with religious perspectives as cognitive authorities for justifying their rejection of evolution. Four out of nine student participants in this study explained that they used the Bible as the authoritative source of knowledge and thus any explanations that seem to contradict its accounts have to be rejected. Nicha explained that when she started learning biological evolution, she did not realise that she would later need to justify her decision about whether evolution should be accepted because, at that moment, it did not seem to contradict her (religious) beliefs. It is likely that she perceived both science and religion as her cognitive authorities at the beginning of the study. However, according to her verbal explanations, later on, Nicha explicitly relied only on religion as a cognitive authority, leading to her rejection of evolution when she studied human evolution. She said that this particular content of evolutionary theory was different from what she had been taught from church and read from the Bible. While starting to reject science as a cognitive authority, she leaned

towards religion by consulting other religious believers (individuals as cognitive authorities) as well as reading books that support her faith (texts as cognitive authorities). In the end, she said that the advice from others and knowledge from her readings enabled her to reject evolution confidently and hold her religious beliefs firmly. In addition, based on competing forms of cognitive authorities, Praporn said that she was not sure whether evolution should be accepted or rejected. She explained that while its explanation is reasonable and its evidence is convincing (science as a cognitive authority), religious belief in God's creation held her back from accepting it (religion as a cognitive authority). She expressed that a Biology teacher who is also a Christian would help her solve this confusion (an individual as a cognitive authority)

Despite these examples, there is no intention to claim that religion necessarily leads to rejection of evolutionary theory. Although religious beliefs can influence responses to evolution that include conflict and rejection, it is also known that many people, including scientists and theologians, manage to reconcile religious beliefs with acceptance of evolution and their professional role. For example, a random survey of 1000 American scientists towards the end of the twentieth century uncovered that 39.3% believed in a personal God, with highest rates of disbelief in God not among biologists - who might be assumed, on the whole, to accept evolution - but among physicists and astronomers (Larson and Witham, 1998). Indeed, a range of rationalisations is apparent from the official statements of many mainstream Christian groups - including Catholicism and many of the mainstream Protestant denominations (see the article of Martin (2010) for a review of major US Christian denominations). The ample evidence from these studies point to the diverse outcomes of the influence of religious authority in perceptions of evolution, which can be a result of combined cognitive authorities (both science and religion), or perhaps adopting science as a cognitive authority in the context of evolution while relying on religion in other contexts.

5.5 Research justification and questions

This study therefore focused on student justifications for levels of acceptance of evolution using the framework of cognitive authority. The following paragraphs address how levels of student acceptance of evolution and student justifications were measured in this study.

According to Section 5.2: *Levels of student acceptance of evolution*, there are different ways to classify levels of acceptance of evolution perceived by students (i.e. quasi-continuous scales, binary, ternary and multi-dimensional schemes). However, a preferred classification is chosen from the suggestion of Smith (2010a) which combines the usefulness of both the ternary and multi-dimensional schemes. Nonetheless, apart from the classification of the levels of acceptance, another issue emerges which is the construct of acceptance as discussed in 5.1. As Smith (2010a, p. 534) argues, “acceptance of evolution is an ill-defined construct that has been confused in the literature”. He explains that it is unclear in the literature which constructs of acceptance of evolution are the focus of much work (i.e. accepting it as science, as scientifically valid or as the best current available). To address this issue, Smith (2010a) suggests a possible way to improve the measurement of acceptance of evolution. More explicitly, Smith (2010a, p. 532) proposes a single item measuring acceptance of evolution as “the best currently available scientific explanation”, and I adopted his suggestion as the starting point for the construction of my questionnaire question.

Smith’s original statement is “the modern theory of evolution by means of natural selection is the best current available scientific explanation of the origin of new species from preexisting species”. In principle, this statement should be capable of measuring student acceptance of evolution because it is clear that the term acceptance written here means acceptance as a valid scientific explanation. However, two minor concerns about the statement were considered which led to a slight modification of Smith’s original statement. First, the term *natural selection* is familiar and commonly known by average students, as well as members of the public as the title of the book of Darwin. Students

may therefore know that natural selection has a substantial role in evolution but not know how it works. In addition, I wanted students to have to accept all of the key processes in order to have them say that they accepted evolution (and not just the natural selection part, which after all, does not include the random sources of variation that is still problematic. Based on this, the terms *variation and inheritance* were added to the statement. The second point is the use of the term *the origin of new species* which only refers to macroevolution and does not incorporate microevolution. Therefore a revised statement is “the modern theory of evolution through *variation, inheritance* and natural selection is the best current *scientifically valid explanation of the past and current biodiversity on the planet Earth*” (modified wordings appear in italics).

According to 5.3, some of previous studies provide a set of student reasons for accepting as well as rejecting evolution (e.g. Downie and Barron 2000). However, the reasons provided in the survey instrument are pre-defined by the researchers themselves. Although Clores and Limjap (2006) provide insightful explanations based on interviews with students, the nature of the qualitative study with a small number of students makes their claims too specific to the context of their study. In order to understand student justifications for levels of acceptance of evolution, reasons for accepting or rejecting evolution should be naturally informed by students themselves so that teachers and researchers can develop instructional approaches which meet their need specifically.

Therefore, this study is conducted with two aims in mind. Firstly, in order to provide evidence for levels of acceptance of biological evolution as a scientifically valid explanation. Secondly, to investigate justifications used by students in explaining their level of acceptance, analysed according to the framework of cognitive authority. In addition, it aims to explore possible links between student reasons and levels of acceptance. It aims to explore these with a larger number of students than in earlier bottom-up work, in a religiously heterogeneous context in order to maximise the variety of reasons as well as patterns of responses. Two specific research questions underpin this study:

1. What is the distribution of responses between different levels of acceptance of biological evolution among Thai high school students attending a Christian school?
2. Which forms of cognitive authority do students refer to in justifying their particular level of acceptance of biological evolution and how these can be linked to different levels of acceptance?

I now explain the methods used to answer these questions.

5.6 Research methods

Data collection was based upon a survey instrument of which two questions are of particular interest in this study. These questions were developed according to the explanation in the previous section. In this section, I explain the data collection and analysis protocol.

5.6.1 Data collection

This survey was conducted in a Christian school in Thailand where all students are boys. The student participants, aged in between 15 and 18 years old, were all enrolled in a science-mathematics programme (M4, M5 and M6 levels) in which evolution and concepts related to evolution are taught as part of the biology curriculum. Specifically, biological taxonomy and cell biology are included in the M4 curriculum, comparative anatomy and animal physiology are part of the M5 curriculum, and genetics and biological evolution are included in the M6 curriculum. A questionnaire was administered to individual students in 9 classrooms (3 classes per level). All of the participants were informed that their participation was fully voluntary according to the process discussed in Chapter 3.

Focusing on this particular study, there were two tasks for the participants to complete in the *Acceptance of Biological Evolution Measurement (ABEM)* as shown in Appendix B. First, they were asked to respond on a five-point Likert-scale (five different levels of acceptance) to the statement on biological evolution. Most of the student participants provided an answer to this question, except one who missed it out. Second, they were asked to provide reasons for

their selection of this particular level based on a written task. The actual question was “Please explain why you have selected this answer?” Over two thirds of the participants provided a short sentence, most of which can be identified as student justifications for levels of acceptance of evolution.

5.6.2 Data analysis

In order to analyse the distribution of responses between different levels of acceptance of biological evolution among the student participants, a descriptive statistical analysis based on frequencies was employed. Two sets of analysis were carried out: an overall distribution of levels of acceptance within the sample ($N = 326$)¹³ and a comparison between the distributions of 217 Buddhist and 97 monotheistic students. The results are presented in the form of a bar chart.

In order to analyse the written responses concerning student justification of the different levels of acceptance, *template analysis*, an approach for organising and analysing textual data according to *a priori* themes (Crabtree and Miller, 1992), was employed. I used the themes proposed by Abd-El-Khalick (2012) concerning aspects of the nature of science as described in Section 5.4 as an initial template. The process of template analysis was carried out as follows. Firstly, I read all of the written responses ($N = 208$) to familiarise myself with the content. This allowed me to distinguish 173 informative (i.e. interpretable accounts regarding justification for selecting a particular level of acceptance) from 35 uninformative accounts (e.g. “I just agree”, “I don’t know” and “I’m not sure”). Secondly, I grouped accounts that were not captured by the initial template into new themes. Third, I developed a final template (see Table 5.3) by adding the new themes to the initial template. At this stage, I made sure that none of the informative accounts were left uncoded.

¹³ The total number of student participants in this survey is 327. However, one participant did not respond to the tasks concerned in this chapter and was excluded from the analysis.

Themes	Examples of student responses
Evidence	Evolution is accepted because forms of evidence support it.
Best explanation	Evolution is accepted as a currently valid scientific explanation of the diversity of life forms.
Consensus	Evolution is accepted among scientists and the scientific community.
Consistency	Evolution is accepted because its explanations are consistent with other scientific theories.
Uncertainty	Evolution is not (fully) accepted because it is subject to change
Ambiguity	Evolution is not (fully) accepted because it cannot be proven
Disagreement	Evolution is not (fully) accepted because many argue that it did not happen.
Acceptance of scientific claims	Evolution is accepted because it is reasonable and convincing. Evolution is accepted because it can explain how different life forms emerged
Rejection of scientific claims	Evolution is not accepted because it is not possible to explain how life forms emerge
Religion as a cognitive authority	Evolution is not (fully) accepted because it contradicts the creationist account of divine creation. Evolution is not (fully) accepted because it does not acknowledge the role of divine power
Refusal of religion	Evolution is accepted because it is more reasonable than religious beliefs.

Table 5.3: Final template for coding student justifications for levels of acceptance of evolution

5.7 Findings

5.7.1 Student acceptance of biological evolution

As shown in Figure 5.1, the analysis shows that over 60% of the student participants (N = 326) accepted biological evolution, of which 19.7% strongly accepted and 40.8% accepted it with some reservation. About one third of the sample (33.1%) were unsure about it. Furthermore, 21 students (6.4%) rejected it of which three strongly rejected and 18 rejected some parts.

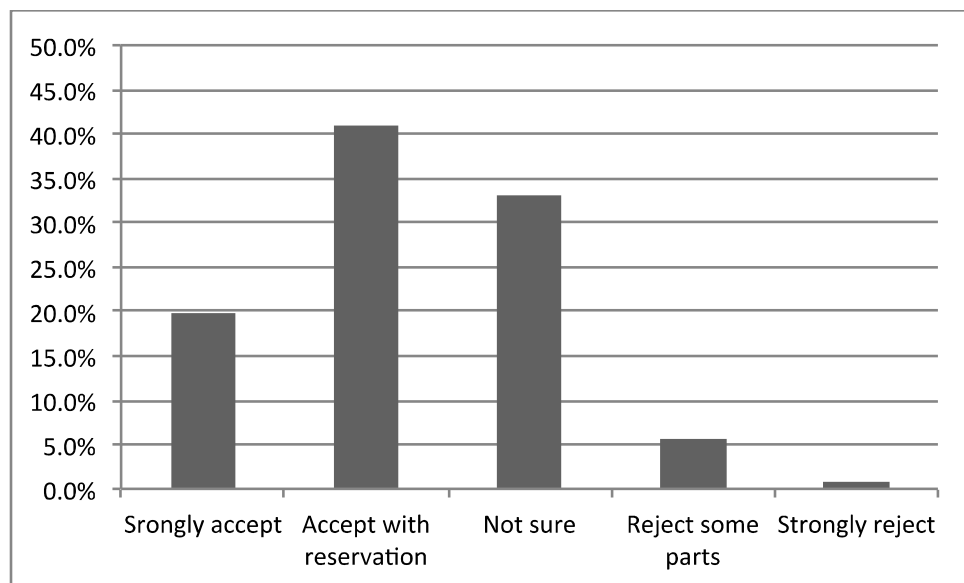


Figure 5.1: Levels of student acceptance of biological evolution

Figure 5.2 shows the breakdown by religion. The analysis shows that among 217 Buddhist students, almost half (48.8%) accepted biological evolution with reservation while about one quarter (25.3%) either strongly accepted or were unsure about it. A greater diversity is found among 97 theistic students, mostly Christians and two Muslims. While about half of them (50.5%) were unsure about biological evolution and about 20% rejected it, almost one third expressed their acceptance (23.7% accepted the statement with reservation and 6.2% strongly accepted it). Those students who did not identify their religious orientations (N = 4) and those who selected either agnosticism or atheism (N = 8) were combined in “other”. Among them, over half accepted evolution, while the rest were unsure or rejected some parts.

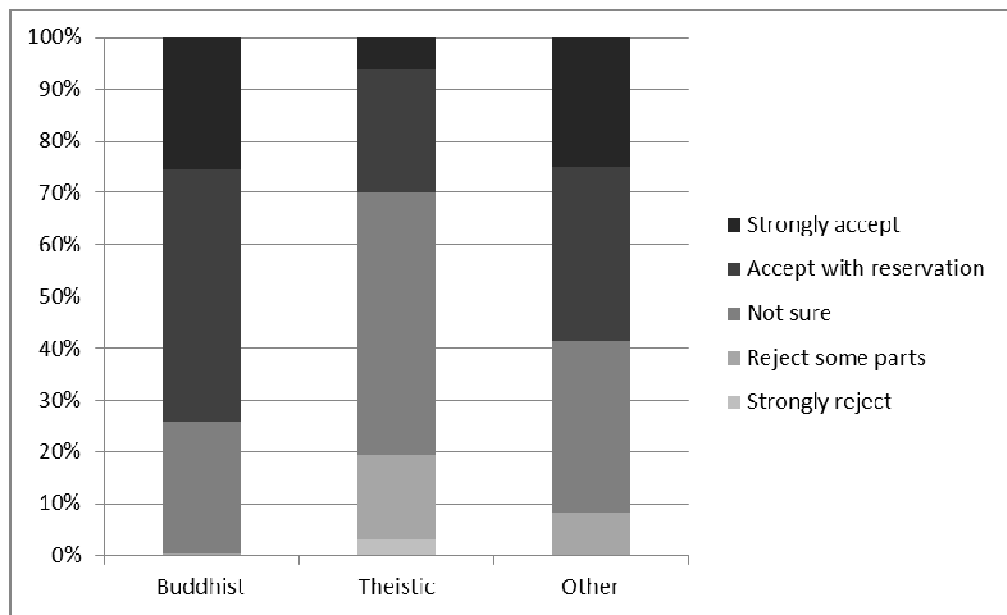


Figure 5.2: Student acceptance of biological evolution in relation to religious beliefs
(Buddhist students = 217, Theistic students = 97, Others = 12)

This dataset points to at least three important findings. First, it suggests that the statement proposed in the questionnaire is readable and effective for the students to understand. This claim is made based on the fact that no further clarification of the statement itself was required during the data collection. In addition, 326 out of 327 students provided a response to this task. In fact, it is unknown whether the only student who did not provide a response found this statement difficult to understand or simply did not wish to answer. However, further clarification was needed for the levels of acceptance, in particular for the difference between “accept with reservation” and “reject some parts”. I return to defending the claim that it is an advantage rather than a disadvantage to include these two levels in Section 5.8: Discussion.

Second, it shows that the five levels of acceptance of biological evolution previously suggested by Smith (2010a) based on theoretical assumptions empirically existed in this study. To be more specific, two additional levels of acceptance (i.e. “accept with reservation” and “reject some parts”) which were not made explicit in the previous work, were selected by a number of students in this study. This suggests that acceptance of biological evolution is not binary. Classifying learners as acceptors or rejecters therefore lacks validity. In fact,

including “reject some parts” in the choices reveals that those rejecting evolution tend not to reject the whole statement outright, but only some parts.

Third, although over 70% of the Buddhist participants accepted biological evolution, the majority of them accepted it with reservation rather than strongly accepting it. In addition, although 70% of the Theistic students did not accept biological evolution, the majority of them were unsure rather than rejecting it. In fact, among the Theistic students who rejected biological evolution, most of them rejected some parts rather than the whole.

The next section considers justifications for this reservation and lack of certainty which are presented as different forms of cognitive authority associated with the different levels of acceptance of biological evolution by the students. To make the pattern of student religious beliefs and justifications for selecting a particular level of acceptance somewhat clearer, a code followed by a tagging number of each participant is given to each written statement; for example BD76 means a Buddhist student whose given number is 76. The same system is used throughout this analysis. However, the initials are different: TH refers to Theistic students, NT non-theistic students (i.e. agnostic or atheist) and UN students with unidentified religious beliefs.

5.7.2 Student justifications for levels of acceptance of biological evolution

In this section, student justifications for the levels of acceptance of biological evolution are presented in conjunction with the different levels of acceptance consisting of strong acceptance, acceptance with reservation, being unsure, and rejection. In the level of rejection, those selecting “reject some parts” and those selecting “strongly reject” were combined because of the very low number of those strongly rejected evolution ($n = 3$). The summary of the findings is shown in Figure 5.3 and the following subsections present detailed findings.

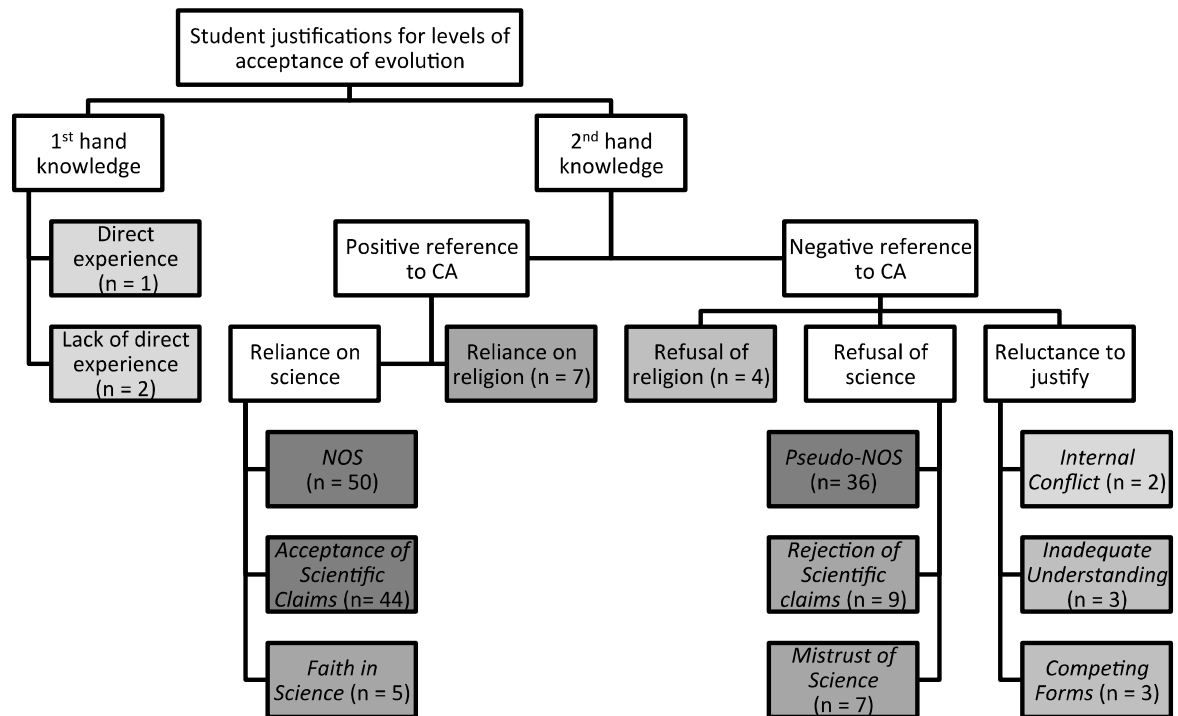


Figure 5.3: Summary of student justifications¹⁴ for levels of acceptance of biological evolution (CA = cognitive authority and NOS = the nature of science)

5.7.2.1 Justifications for strongly accepting biological evolution

In sum, while one student strongly accepted biological evolution based on first-hand knowledge, most of those strongly accepting the statement for biological evolution justified their level of acceptance based on second-hand knowledge in the form of science as a cognitive authority through four aspects of *the nature of science* (NoS), (de facto) *Acceptance of Scientific Claims*, and/or *Faith in Science*.

First-hand knowledge based on direct experience

One student (TH9) justified his strong acceptance of evolution through first-hand knowledge as he explained from his direct experience that he has carried

¹⁴ Category names of student justifications at the level of specific forms of cognitive authorities are in italics and the gradient shading represents the proportion of students.

out “a science project on molecular biology before so [he believes] that evolution really happens”.

Reliance on science as a cognitive authority based on NOS

On this particular basis, many of the students who strongly accepted biological evolution justified their strong acceptance through aspects of *NOS* composing *evidence*, *best explanation*, *consensus*, and *consistency*.

More specifically, first, the highest number of students (n = 16) referred to *evidence* for evolution when justifying their strong acceptance of evolution. Relying on this *NoS* aspect, some considered that the theory of evolution has been continuously tested and supported by a collection of evidence (TH311, BD252, BD162, BD139, BD37, BD274, UN196), as well as a series of empirical studies (BD63, BD283, BD281, BD255, BD68). For example, TH311 wrote that “many biologists have proven it and a range of evidence shows that evolution happens”, BD283 that “this has long been studied and it has been taught from generation to generation” and BD68 that “this is scientific truth which is verified by experiments conducted by scientists”. BD251 includes all of these aspects in his explanation that “this is supported by scientific experiments, valid hypotheses and good evidence”.

Second, four students justified their level of acceptance through the *consensus* of evolution within the scientific community which includes a diverse range of authoritative forms - individuals (e.g. BD173 and TH10 strongly accepted the theory because it is scientifically accepted by a number of people including scientists), formal science education (e.g. BD156 accepted evolution because of its inclusion in internationally accepted science curricula), and the scientific enterprise (e.g. TH205 viewed that “this theory meets the standard of scientific research”). Third, three students justified their strong acceptance through *best explanation*, perceiving that evolutionary theory is the best currently available scientific explanation based on human endeavour (BD183) and “no other theories can discredit it” (both BD5 and BD143).

Another aspect of *NoS* was referred by BD279 and BD177 as they explained that they could see the link between the proposed statement representing evolution and other scientific theories that they have been taught from school so that this *consistency* makes them strongly accept the statement. Additionally, when students justified their level of acceptance through *evidence*, this was usually found alongside one of the previously discussed aspects of *NoS*. For example, BD224 combined *evidence* with *best explanation* expressing that “there is no other good alternative available at this time and this theory has been proven by experiments conducted by scientists”. BD165 combined *evidence* with *consensus*, explaining that “this is provable and many people believe in this”.

Reliance on science as a cognitive authority based on de facto *Acceptance of Scientific Claims*

Instead of pointing to one of the particular aspects of science, another group of students ($n = 17$) who strongly accepted evolution and justified their level of acceptance through *Acceptance of Scientific Claims*. Seven expressed their reasons in this form employing generally accurate understanding about evolutionary processes (i.e. genetic variation, mutation and natural selection) to support their justification. Among them, three somewhat accurately provided an explanation associated with the concept of genetic variation (BD286, BD175 & BD144). For example, BD286 wrote “diversity of life does really exist as we all can see it. This indeed stems from genetic variation within organisms”. In addition, one student explained a mechanism leading to genetic variation: “diversity of life comes from the crossing over of chromosomes. In this process, there are exchanges of genetic material (BD210)”. Moreover, BD42 provided a more complete explanation as he wrote ‘evolution is about genetic variation such as mutations of genetic traits. Any traits that pass on in a certain environment at a certain period will be able to reproduce and continue to live according to the concept of natural selection’. In addition, another two students wrote that “mutation is found in organisms existing today” (BD190) and “natural selection is the factor for evolution of organisms” (BD89).

However, strong acceptance was not always associated with accurate understanding, as another two students appeared to hold a misconception

associated with Lamarckian inheritance regarding physical adaptation. NT256 wrote “only those who are stronger and more ready will be able to live in the new ages to come. We all have to adapt ourselves to the uncertain future”. BD33 said “because all living things have adapted and learnt from things surrounding them. This adaptation leads to competition among them in order to survive and this competition leads to the diversity of life”. Taken together, these two examples indicate that acceptance of evolution is not always a mere result of accurate understanding of the content of the theory but can be also underpinned by inaccurate knowledge.

Finally, instead of referring to an element of understanding, some students justified their strong acceptance of evolution through their agreement with the statement for biological evolution used in the research tool. Three students (BD51, BD 65 & BD 77) believed in the *convincingness* of the statement. Another four students agreed that the statement makes reasonable sense to them (BD199, BD197 & BD131); and this sense of *reasonableness* makes BD73 “so confident to believe that it’s true”. Additionally, one student combined these two together and wrote “this is the most reasonable and convincing and promising” (BD187).

Reliance on science as a cognitive authority based on *Faith in Science*

Another group of students who relied on science as cognitive authority justified their strong acceptance of evolution through *Faith in Science*. Specifically, BD211 explained that “science is the only thing that [he] can accept”. Similarly, another student explained that he accepted it “because science determines all things” (BD182).

Refusal of religion as a cognitive authority

Two students justified their strong acceptance through refusal of religion. BD64 argued that science is much better than the other rival explanation - religious - as he said “this is not about God so that it is the best”. Additionally, BD127 combined *evidence* with his refusal of religion as he argued that “science has experiments to support its explanation which make it more certain, clearer and far better than religious claims”.

5.7.2.2 *Justifications for accepting biological evolution with reservation*

Two broad sets of rationales were identified in relation to their levels of acceptance of the statement for biological evolution. One was associated with justifications for acceptance of the statement (i.e. reliance on science as a cognitive authority based on *NoS*, *Acceptance of Scientific Claims*, and *Faith in Science*); the other associated with those justifications for reservation (i.e. refusal of science as a cognitive authority based on *Pseudo-NoS* and reluctance to provide a justification based on *Internal Conflict*).

Reliance on science as a cognitive authority based on *NoS*

To begin with those positively referring to science as a cognitive authority for accepting the statement with reservation, the analysis shows that about one third of the students justified their level of acceptance on the basis of *evidence* (n = 15), *best explanation* (n = 4) or *consistency* (n = 3). However, justifications through *consensus* were not present in this group. In addition, unlike the previous group of students, combining *evidence* with other *NoS* aspects was not predominant among these students. There were only two who expressed combined justifications. BD261 integrated *evidence* with *reasonableness* (i.e. a form of de facto *Acceptance of Scientific Claims*) explaining “it is reasonable and supported by scientific experiments. Molecular genetics is becoming advanced and it makes this claim even stronger”. BD246 employed *evidence* and *consistency* as he wrote “this is supported by scientific experiments and is perfectly linked with other existing scientific theories”.

Reliance on science as a cognitive authority based on de facto *Acceptance of Scientific Claims*

There is not much of a difference in student justifications for accepting biological evolution through *Acceptance of Scientific Claims* between those who strongly accepted and this group of students who accepted it with reservation. It can therefore be assumed that student understanding might lead some students to accept evolution; however, it appears that it does not necessarily lead to strong acceptance. Seven students agreed with the statement that biodiversity comes into being “through genetic variation from generation to

generation” (BD248 and BD27) led by natural selection (BD166) over a period of time (BD294). In addition, BD69 understood that “changes of organisms” result from “parental genetics”. Additionally, BD233 highlighted that “in the biological world, organisms exchange their genetic information through cross reproduction”. Relying on knowledge in genetics, BD229 also argued that “there is a huge number of species in this planet and they all share the same genetic system, and some of their DNA sequences are identical”.

Five individuals justified their acceptance of biological evolution with reservation through references to environmental determinism and physical adaptation (Lamarckian misconceptions). For examples, BD179 wrote that “organisms have to develop themselves because of the changing environment” (BD106 also described something similar) and BD54 said that “the environment determines the change and adaptation of organisms”. Interestingly, one student integrated his Buddhist precept in this misconception as he explained that “the environment determines the diversity of the genetic information of each individual person. This depends on the cycle of karma according to what the Lord Buddha taught” (BD134). Another student understood that “organisms evolved because they had to survive [from being] threatened in nature” (BD118).

I turn now to those whose justifications relied on *convincingness* (n = 9) and *reasonableness* (n = 2) of the statement for biological evolution. Interestingly, a striking contrast between these students and those who strongly accepted the statement for evolutionary theory on the basis of these two aspects becomes evident. Those strongly accepting tended to describe the *reasonableness* and *convincingness* by using the verb “is” such as “it *is* the most reasonable (BD197), with only one exception” (BD131). In contrast, only two out of the 11 students accepting with reservation provided this form of expression (BD40 and BD206); but the rest appeared to be less confident as they used weaker expressive verbs. For examples, “this *sounds* reasonable” (BD239, BD184), “I *feel* that it is scientific” (BD222), “it *sounds* unbiased” (BD316, BD66, BD141) and “this *sounds* unproblematic and I *think* I’m happy with this” (BD309). In addition, BD257 expressed his weak support of this theory as he wrote “this explanation *might be able* to explain evolutionary process and it is *most likely possible*”. Similarly,

BD155 said “this *sounds* very good and it *might be able* to explain about the diversity of life”.

Reliance on science as a cognitive authority based on *Faith in Science*

Another five students justified their acceptance of biological evolution with reservation through *Faith in Science*. However, compared to the previous group of students, no additional observations were obtained from these students' explanations.

Refusal of Science as a Cognitive Authority based on *Pseudo-NoS*

Rather than providing reasons for accepting biological evolution, one third of the students (n = 21) in this group chose to explain their justifications for being reserved from strong acceptance. Their justifications were made through two aspects of *pseudo-NoS*: *ambiguous* or *uncertain*. To be more specific, 17 of them referred to the lack of clarity of the theory, claiming that some aspects of the theory remain “unclear” (BD260, BD188, BD25), are not yet or cannot be “completely proven” (BD269, TH98, TH2), might not be “entirely true” (BD245, BD232, BD225, BD151, TH3) and are not “conclusive” (BD249, BD85). In addition, BD226 and BD220 referred to a combination of these as they wrote “I don't think it is completely right; many parts are to be proven” and “some aspects of the theory remain unclear and cannot be proven”, respectively. Additionally, although identifying himself as a Buddhist, BD244 attempted to highlight *ambiguity* in the light of theistic belief as he explained “although this [evolution] is claimed to be widely accepted in scientific journals, God might be the Creator. But the journals don't accept this non-scientific idea. I reserve judgement because there is always unknown truth”. Moreover, UN300 noted that there is a range of ways to explain reality and science is only one of the ways; therefore, he wrote “science is only a kind of knowledge constructed by scientists. It is impossible that only science itself can make everything known to humanity. We therefore should believe in science as it is knowledge but should not have faith in it”.

Another four students claimed to be reserved because they perceived the *uncertainty* of evolution. BD273 wrote that “it is still changeable” and BD34 that

“scientific knowledge is still in progress”. More specifically, BD174 clearly said that “what I’m not sure is about the certainty of the theory”. Along similar lines, although BD49 viewed that the explanation is “the best at this moment”, the fixed period of time in the wording provided (i.e. the best ‘currently’ available) makes him reserved as he further explained that “it means that this theory can be changed whenever a better one comes along”.

Reluctance to make justification based on *Internal Conflict*

Interestingly, BD80 expressed that he accepted evolution as a scientific explanation of changes in life forms based on genetic variation and natural mechanisms. However, knowing this as a valid explanation did not make him satisfied because he could not find the purpose of life by accepting it. Although this form of *Internal Conflict* has nothing to do with the understanding of particular aspects of biological evolution, it is related to perceived negative impact of accepting evolutionary theory.

5.7.2.3 Justifications for being unsure about biological evolution

Those who answered that they were unsure about the statement of theory of evolution (n = 35) justified their level of acceptance in one of these four different aspects: lack of first-hand knowledge, refusal of science as a cognitive authority (based on *Psuedo-NoS*, *Rejection of Scientific Claims*, and *Mistrust of Science*), reliance on religion as a cognitive authority, and reluctance to justify (based on *Internal Conflict*, *Inadequate Understanding*, and *Competing Cognitive Authorities*)

Lack of first-hand knowledge

Instead of explicitly accepting or rejecting biological evolution, two students seemed to justify their level of acceptance based on first-hand knowledge which is only reliable to them. The students mentioned that they had no personal experience of evolution and thus they were unable to make any justification about the statement. Their accounts may sound naïve; however these reflect their denial to make a justification based on lacking personal experiences. The accounts were “because I wasn’t yet born by that time” (NT214) and “I have never proved it for myself” (TH2).

Refusal of science as a cognitive authority based on *Pseudo-NoS*

Over one third of those selecting “unsure” interpreted the tentative nature of the theory of evolution as a possible weakness in terms of *ambiguity* and *uncertainty*. Those who viewed the theory as ambiguous claimed that it remains unclear (TH4), it “contains some unknown aspects” (BD284, BD142), it “might not be entirely true” (BD272), it remains “untested” (TH324, TH104, TH14) and it “might be another set of beliefs” (BD84). Those who referred to uncertainties in relation to the theory of evolution made claims relating to the possibility of changes to the theory and the limitations of science. Notably, it is found throughout this analysis that ambiguity and uncertainty are closely related. TH11 combined both elements in his expression as he wrote “at this present time, the advancement of science and knowledge of humans are limited, so people conclude it like this. In the future, knowledge and understanding of humans will increase; this explanation therefore will be definitely changed”.

Refusal of science as a cognitive authority based on *Rejection of Scientific Claims*

Five of the students who selected “unsure” justified their level of acceptance through direct rejection of the statement for biological evolution or rejection of science and evolution in general. For example, BD124 wrote “it [the statement] cannot be concluded like this”. TH97 wrote “this [the statement] sounds impossible”. Another two students said that science (for BD181) or evolution (for BD132) is “unable to explain the origins”. It seems that BD39 is less strong on this view; however he still has no trust in evolution as he wrote “science can only explain genetic materials, but not evolutionary processes”.

Refusal of science as a cognitive authority based on *Mistrust of Science*

Two of the students who selected “unsure” explained that they chose this level of acceptance because they simply do not trust scientists and scientific claims about evolution. For example, TH290 wrote that “science is not always right”. TH87 wrote that “this [theory] lacks clear evidence but relies solely on scientists' fancy imagination”. His mistrust was in relation to both evidence and scientists themselves.

Reliance on religion as a cognitive authority

Two students in this group justified their “unsureness” about biological evolution through religious perspectives. TH325 wrote “the Bible tells a different story from this; the theory therefore might be true or might not”. Although he takes the Bible as the source of his rationale, this student does not reject evolution straightaway, but remains unsure. Another expression was provided by TH312 who argued that he would have agreed more if “this acknowledged God as the Creator too”.

Reluctance to justify

About one third of the students in this group were reluctant to justify their selected level of “unsure”. Through *Internal Conflict*, TH18 said that “I'm not sure about my faith and things told by others”. Apart from this, there were other three students whose reluctance to justify arose from *Inadequate Understanding* of the theory of evolution. The students said that their knowledge gained from biology classrooms is too limited; and thus they really do not know whether the statement provided is right or wrong (TH313, TH263 & BD305). In contrast, another three students were reluctant because of perceived *competing forms of cognitive authority*. More specifically, relying on individuals as the form of cognitive authority, BD303 wrote that “a number of scientists have confirmed that this theory is true. But many still argue against this”. TH304 explained something similar but did not specify who the individuals are: “it is confusing because there are those who believe in evolution and those who do not”. Two different forms of authority (one is texts and the other individuals) become the source of reluctance for BD88 who described that “it is said in science textbooks that genetic variation leads to evolution; but many people keep providing evidence against it”. In addition, TH107 explained, rather candidly, that “because it's just so confusing, I don't want to think about it”.

5.7.2.4 Justifications for rejecting biological evolution

The number of those who rejected the statement on evolution is relatively low (n = 21). However, about three quarters of this group provided written expressions for their justification which is the highest proportion compared to

the other groups. Among these students, only 1 strongly rejected (TH302) while the rest rejected some parts (n = 14). It is also important to note that 13 of these students are Christians. Their justifications can be classified in two broad groups: those associated with refusal of science as a cognitive authority on the basis of *Pseudo-NoS* (n = 2), *Rejection of Scientific Claims* (n = 2), and *Mistrust of Science* (n = 9) and those relying on religion as a cognitive authority (n = 4). More details are provided below.

Refusal of science as a cognitive authority based on *Pseudo-NoS*

Two students rejected evolution because they remained sceptical about the nature of science. One did not accept the statement because he perceived that “there are many alternative explanations in science and this [statement] might be wrong” (TH110). It might be possible that the student’s expression somewhat corresponds with *ambiguity* based on his perceived possible “wrongness” of evolution. Considering this with his rejection, it is likely that he tried to communicate that the other alternatives (which could be pseudoscience or religious claims) are more acceptable than the statement provided. Another student stated that “in the future, there might be another theory which either destroys this or proves it true, it is still uncertain” (UN254). Indeed, this can be aligned with *uncertainty* as previously described.

Refusal of science as a cognitive authority based on *Rejection of Scientific Claims*

Another two students simply rejected the scientific explanations of biological evolution without giving any rational clarification. TH171 wrote “genetic variation might not be able to make organisms mutated”. In addition, TH12 wrote “I did not accept because the statement says that the diversity of life comes from evolution”. Both of them used the same foundation to reject the theory which is the rejection on the ground of their perceived “wrongness” of the statement. The former restated a term used in the statement (genetic variation) while the latter rephrased the first half of the sentence by using the term “evolution” instead. After doing so, both pointed out that they did not find this point of the sentence convincing and thus rejected the statement. However, although they attempted to argue against the statement, their explanations

were uncritical and even factually wrong. Another four students also rejected biological evolution as they found the statement unconvincing. However, their expressions are stronger and more condemning - “it is only a kind of faith” (TH315), “it is too biased” (TH319), “it is a joke” (TH320) and “no way” (TH321). Apart from this sense of rejection of the scientific explanation of biological evolution, none of them provided rationales or support for their claims.

Refusal of science as a cognitive authority based on *Mistrust of Science*

Furthermore, justifications of other five students are aligned with *Mistrust of Science*. For example, TH327’s mistrust was in scientists as he wrote “scientists are not the most intelligent people”. Furthermore, another participant referred to “science” as an abstract institution and argued that it “can’t answer everything” (BD76). These students explicitly make their rejection towards scientific authority but in different forms.

Reliance of religion as a cognitive authority

Four students rejected biological evolution on the basis of adopting an alternative authority specifically in the form of monotheistic belief. Two of them were found to be influenced by a literal interpretation of the Bible. One wrote “the Bible says that God created the heaven and the earth” (TH122). Another student wrote “I believe as it is written [in the Bible] that God created every single kind of animals specifically” (TH231). In contrast, another two students did not mention the religious book directly. Their rejection was made as a result of their perception that statement is incomplete. In other words, rather than rejecting evolution outright, these students explained that the statement itself does not capture their view. As TH308 explained, he rejected the statement because “it does not value the role of the Creator who designs [evolutionary processes]”. The other said that he “would have agreed if it said that God allows this to happen” (TH322). It is possible that these two students accepted evolution as a divine process leading to the diversity of life forms on the planet earth (technically called either theistic evolution or evolutionary creationism). It is likely that they would feel more comfortable and might accept the statement if it included a reference to the Creator (e.g. God, supernatural being, or intelligent designer).

5.8 Discussion

This section is divided into two subsections so as to discuss the findings and their implications in an orderly manner. The first subsection discusses the findings that answer the first research question which focuses on the distribution of responses concerning different levels of acceptance of biological evolution among the participants. Following this, the implications suggested by these findings are discussed. The second subsection covers student justifications for levels of acceptance of evolution.

5.8.1 Different levels of student acceptance of biological evolution

In order to respond to the first research question focusing on the distribution of responses between different levels of acceptance of biological evolution among the student participants, the findings reveal that over 60% of the participants accepted the statement for biological evolution. Among them, two thirds accepted evolution with reservation and the rest strongly accepted it. Over 30% of the student participants were unsure about evolution. Finally, less than 10% of the participants rejected evolution. However, rather than rejecting it as a whole, they were likely to reject only some parts of evolution.

These findings demonstrate that the majority of those accepting evolution tended not to strongly accept it but hold some reservation. Along these lines, another interesting finding is that those rejecting evolution tended not to hold a strong rejection view but made their rejection specifically to some parts of evolution. This therefore supports the claim that a binary logic for classifying student opinions of the acceptance of evolution is misleading. Thus, labelling students as “acceptors” or “rejecters” seems to be oversimplified and unnecessarily strong. In addition, this points to the importance of the next section which discusses student justifications for the levels of acceptance of evolution. However, before moving to the next section, it is interesting to examine a response from one student in the following paragraphs which shows a connection between the two cases (i.e. those accepting evolution with reservation and those rejecting some parts of it).

During the first session of data collection, one of the M5 student participants asked a question among his peers while he was completing the questionnaire. He was unsure whether the two levels of acceptance of evolution provided in the questionnaire are different which are “accept with reservation” and “reject some parts”. His concern was that these two choices are not different because those who are reserved from strong acceptance of evolution should be those who rejected at least a part of the theory. In other words, those who are reserved because they find something of the theory of evolution difficult to accept.

My immediate response to his concern was that the two choices might not be literally different; however, they are psychologically distinguishable. An illustration of a glass containing a half of water worked well in this case. Using this illustration, the students were explained that while a group of people might perceive the glass as “half full”, another group might perceive it “half empty”. Psychologically speaking, the former might represent the optimists, whereas the latter the pessimists. Linking to the context of evolution education, although those accepting evolution with reservation and those rejecting some parts of it might share the same attitude that there is something making them refrain from accepting evolution, their different selections stem from the different psychological reasons and yield different outcomes. While those accepting with reservation tend to view that there might be something in the theory of evolution that is unclear to them, they choose to accept evolution, perhaps based on what is clear. In contrast, those rejecting some parts tend to consider these rejected parts more serious and use them as reasons for rejecting evolution, perhaps based on their negative views towards evolution having in the first place.

My rationale explained above makes me confident that there is no need to rewrite the two choices in the questionnaire as they are literally understandable and psychologically effective because there was no issue of understanding in the other classes. However, what needs to be done in the future is to find a way to explain to participants what these two choices mean. The illustration of the glass containing half water might be worth considering as one of the possible

ways to convey the difference between the two. Furthermore, while being convinced that the two choices are effective, this current case draws me back to the creditability of previous studies which also use a five-Likert scale item but include different labels (strongly accept, accept, not sure, reject, strongly reject). While the far left, middle and far right labels (i.e. strongly accept, unsure, strongly reject) may be similarly understood across studies, I argue that “accept” is different from “accept with reservation” and “reject” is psychologically different from “reject some parts”. It is possible that in previous studies when students expressed their rejection to evolution, they might not reject it as a whole. However, they were arbitrarily labelled as “rejecters” solely because research instruments forced them to be. In fact, they may accept some aspects of evolution, but this descriptor of a position was not available in the research instrument.

Therefore, further suggestions from this section are concerned with future studies using this categorisation of the different levels of acceptance of evolution in different settings in order to explore whether the same pattern of responses is observable, as well as implementing this research instrument in settings where previous studies were carried out in order to examine whether findings to be obtained from *ABEM* are comparable to the previous ones.

5.8.2 Different forms of cognitive authority influencing student justifications for levels of acceptance of biological evolution

This section provides answers to the second research question concerning forms of cognitive authority to which students refer in justifying their particular level of acceptance of biological evolution and how these can be linked to different levels of acceptance. The findings show that student justifications for the levels of acceptance can be broadly divided into two groups based on either first-hand or second-hand knowledge. Most of the student justifications are associated with second-hand knowledge which appears in the forms of relying on science or religion as a cognitive authority or refusing one of them as a cognitive authority. More specifically, there were those who justified their acceptance of evolution through relying on science as a cognitive authority using *the nature of science* (NOS), (de facto) *acceptance of scientific claims*, and/or *faith in science*, or

refusing religion as a cognitive authority. In contrast, there were those who justified their non-acceptance of evolution (i.e. reservation, unsureness or rejection) through refusing science as a cognitive authority using *pseudo-NOS*, *rejection of scientific claims*, and/or *mistrust of science*, or relying on religion as a cognitive authority. In addition, there were those who were reluctant to justify whether biological evolution should be accepted or rejected through *internal conflicts*, *inadequate understanding*, and *competing forms of cognitive authority*.

The findings from this present study demonstrate that those accepting and those not accepting evolution tended to consider similar aspects of evolution when making their justifications. However, their justifications on these similar aspects are somewhat opposite. One justification leads to acceptance of evolution; whereas another leads to reservation, unsureness or rejection of evolution. A summary of these opposite justifications found in this study is shown in Figure 5.4. I focus first on the largest group of students in this study which is those whose justifications are associated with *NOS* aspects. The findings show that while evolutionary theory is perceived by many as *best explanation*, the best currently available scientific explanation of the origin of life forms, some perceived *uncertainty*, arguing that evolution is still uncertain and its explanation will be changed over time. In addition, while *evidence* for evolution is perceived by many as overwhelmingly consistent and clear, there were some who viewed that it is full of *ambiguity*, having some aspects unproven. While there were those who described the *consensus* of evolution which is the common agreement of the acceptance of evolutionary theory within various representations of the scientific community including scientists, scientific texts and science education, there were those who expressed *disagreement*, viewing that although evolution is accepted by many, it remains rejected by others. Interestingly, some justified their acceptance of evolution through *consistency* or the connectivity of the theory of evolution with other scientific explanations. However, none of those not accepting evolution expressed an opposite view for this.

Turning to those whose justifications are related to the scientific enterprise as well as scientific claims, while there were those who expressed *Faith in Science*, arguing that science is the only type of knowledge that they can accept, there were those who simply expressed *Mistrust of Science*. In addition, while there were those who relied on *Acceptance of Scientific Claims* by specifically focusing on some elements of conceptual understanding about evolution or holistically expressing the idea that evolution is convincing and reasonable, some relied on *Rejection of Scientific Claims*, arguing that evolution is unable to explain the origins or that specific claims are untrue. In addition, while there were those who accepted evolution on the basis of refusal of religion as a cognitive authority, there were those who did not accept evolution on the basis of reliance of religion as a cognitive authority through literal interpretation of the creationist accounts as well as theistic perspectives of evolution. Finally, there was one student who accepted the theory of evolution based on his expression of first-hand knowledge and experience in scientific research on evolution; however, there were some who did not accept evolution because they lack of this kind of first-hand experience.

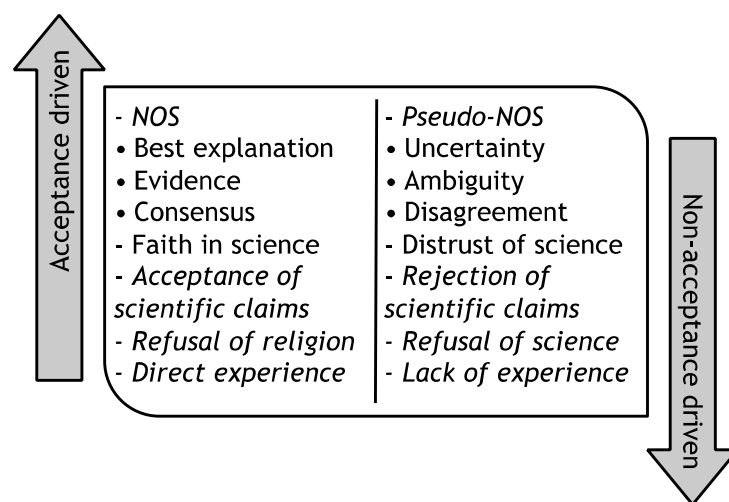


Figure 5.4: Student justifications for accepting and not accepting evolution. Sub-elements of NOS and pseudo-NOS are shown with bullet points.

The opposite justifications are now specifically discussed in the light of educational implications. First, I focus on those who perceived the opposition

between *best explanation* and *uncertainty*. I understood from the written responses given by the students that this opposite justification arose from the phrase “the best currently available” in the statement used in the questionnaire. The phrase appears to be wrongly perceived by some students who did not accept evolution as a weak aspect of the theory of evolution or *uncertainty*. To them, instead of viewing its potential for being improved in the future when scientific knowledge becomes more advanced, they emphasise the changing nature of the theory of evolution due to its “incompleteness” which makes them either reserved, unsure or reject evolution. For example, TH11 explains that “in the future, knowledge and understanding of humans will increase; this explanation therefore will be definitely changed”. His emphasis on evolution as subject to change makes him unsure about it. This danger of partial understanding of the nature of science as tentative is also found in the expression of BD49 who is reserved about the acceptance of the theory on the basis of its potential to be changed “when a better one comes”. This raises another concern for science teachers and educators that it is needed to point out clearly and carefully to students that knowledge of science is tentative, not certain; however, tentativeness does not imply the limitation of scientific knowledge in the sense of guessing. In fact, scientific knowledge becomes stable over time through a collection of new observations which allow scientist to adjust or reframe previous explanations to be more solid. In addition, this process applies to all scientific theories which scientists view as a developmental pathway of scientific knowledge, not the weak point for making negative justifications.

Second, I focus on those who perceived the opposite justifications between *evidence* and *ambiguity*. By possessing a sense of *ambiguity* (e.g. unknown aspects, unseen facts, incomplete evidence), some students are either reserved, unsure or reject the theory. Dagher and BouJaoude (2005) also discuss a group of students who hold this view. They explain that “historical types of evidence were not seen by most students as trustworthy because they do not conform to the standards students have come to associate with things scientific” (p. 387). This points to a serious misunderstanding among the students in relation how to evaluate scientific evidence. Science teachers therefore should point out to

students that no single experiment can provide complete evidence and explanations to the biological world. However, collections of evidence are important for developing a scientific theory; and thus, focusing on particular examples of evidence can also misguide students. In fact, this approach is predominantly used by intelligent design movements to oppose evolution. I recommend that the aspect of *consistency* needs to be incorporated to strengthen perceptions of *evidence*. As Dagher and BouJaoude (2005) explain, the method for generating a scientific theory requires a number of steps involving observations and experimentations. In addition, I argue *consistency* can play a significant role in reformulating evolution instruction as none of the students appear to provide a statement against these. However, a strong claim on this should not to be made because of a relatively small number of the students in this study referring to these two aspects of NOS. Nonetheless, it may be worthwhile for further work to investigate how this particular aspect of the nature of evolutionary theory impacts on student views towards the theory.

The third consideration is on the difference between *consensus* of evolution and *disagreement* among forms of cognitive authority. While the sense of *consensus* is based on a diverse range of authoritative forms - individuals, formal science education and the scientific enterprise - the sense of *disagreement* might be based on individuals of religious faith as well as books providing reasons against evolution. However, this does not mean that all individuals are equally valid in terms of being cognitive authorities providing justifications for evolution. This issue might be minimised if students are able to appropriately understand and interpret evidence for evolution written in books or verbally explained by others. Teachers might help students exercise their justification for the validity of evidence of evolution through comparing forms of evidence and explanations in standard science textbooks with other forms of evidence and explanations from newspaper or “popular science” books.

Fourth, I now focus on the opposition between those who relied on science as a cognitive authority through *Acceptance of Scientific Claims* and those who refused science as a cognitive authority through *Rejection of Scientific Claims*. Ideally, science teachers would like their students accept scientific explanations

based on scientifically accurate understanding. However, this study points out there were some students whose justification for accepting evolution is based on misconceptions. Another point of concern is that there were those who believed that evolution through genetic mechanisms cannot bring the diversity of life forms (e.g. TH171 and TH12). Drawing on the literature, it is possible that these students reject the concept because either they misunderstand it or they hold an alternative position. Both kinds of students exist in the study conducted by Yasri and Mancy (2012). They explain that one student misunderstands that human beings evolved from monkeys and she cannot live with this idea and therefore rejects the theory straightaway. On the other hand, another two students correctly understand the theory assuming from their high marks achieved; however, they both reject the theory based on their creationist views and try to learn about it in order to find its limitations for further arguments with peers. Neither acceptance of evolution based on misconception nor rejection of evolution based on misconception is a desirable outcome. Thus, I reiterate the importance of student understanding of evolution again here.

Fifth, I now focus on those whose justifications are related to the opposition between *Faith in Science* and *Mistrust of Science*. While there are those who have perhaps misplaced faith in science, a range of strong objections was given by the students such as objections to scientists (TH327), objections to science itself (BD76 and BD181), and objections to the theory of evolution (TH171, TH290, and BD132). Neither faith in science nor mistrust of science constitutes an appropriate justification for accepting or not accepting evolution because neither demonstrates appropriate use of scientific rationales in the form of evaluation of the weight of the evidence. A lack of skill in evaluating different sources of information may make many students confused because they do not know what authority they should follow and decide to have no view on acceptance of evolution as described by TH313, TH263, BD305, BD303, TH 304 and BD88.

Sixth, a classical issue in evolution education is also found in this study which is the opposition between those refusing religion as a cognitive authority on the ground of scientism and those refusing science as a cognitive authority on the

ground of religious beliefs and creationism. Although, in this study, the attempt was made to explicitly communicate the theory of evolution by a carefully worded scientific statement without any reference to religious belief, there were still some Christian students who rejected the statement on the grounds of religious beliefs, as well as creationism. However, compared to other studies such as Downie and Barron (2000) and Özay Köse (2010), the proportion of those relying on religious reasons is relatively low. This might hint at the fact that when students are allowed to evaluate the acceptability from their personal view (which is negative to evolution), without leading questions that might make them concerned about the controversial issue between science and religion, they tend to rely on other pseudoscientific arguments rather than directly refer to religious reasons. Indeed, we have to accept that it is impossible to make the statement completely neutral because there remain those who interpret it in the light of philosophical and/or theistic perspectives. However, I would recommend science teachers to consider the use of this statement to explain what biological evolution is about to their students. I believe that even those who rejected the statement for religious reasons are not particularly strong in their rejection, assuming from the findings. This is due to the fact that half of those rejecting evolution based on religious reasons explained that they could have accepted the statement more if the role of divine was included in it. It is more likely that these students would like evolution to be explained on the basis of theistic evolution, not purely naturalistic one; however, they did not strongly reject it.

The final point of discussion here is student reservation and rejection of evolution based on *reluctance*. There were those who did not accept evolution because they did not understand it, did not know who to believe when different views about evolution are given, or could not find the purpose of life when accepting it. Lack of understanding was found to arise from the complicated concepts of the theory itself (e.g. TH313, TH263, BD305, TH81, BD24 and BD28) and can be minimised by clear instruction and additional support such as tutorials and question-and-answer sessions. The inability to decide who to consider as a valid cognitive authority, and the perceived negative consequences of accepting evolution, although different challenges, can both be

minimised by a better understanding of the nature of science. Understanding that science produces, demands and relies on empirical evidence would help students to realise that a trustworthy cognitive authority should be that of empirical evidence. In addition, understanding what sort of question science asks would help students see the distinction between scientific questions which can be addressed by conducting experiments and collecting empirical evidence, and philosophical questions of life which cannot be (fully) addressed through these means. Although the proportion of those not accepting evolution is increased because of these students who hold *reluctance*, I argue that they are a potential group of students who might be able to arrive at acceptance of evolution if evolutionary concepts as well as aspects of the nature of science related to evolution are communicated to them clearly.

This chapter raises an important question for further investigation as it points to hidden complexities of interpretation among students who accepted evolution but failed to understand it appropriately. Although it is not unusual for students to hold some misconceptions about evolution, accepting it with little understanding shows a rather unsatisfactory learning outcome. In addition to this educational concern, from a more philosophical perspective, I am concerned that some students may develop a belief in evolution based on misconceptions in the sense of “worshipping” evolution as a “religious belief” as discussed by Midgley (1985). I therefore suggest that instructional strategies should include opportunities for students to reconsider and evaluate their initial ideas about evolution as well as the nature of science. Similar to the other misconceptions, it is necessary for students to be able to distinguish science and some aspects of pseudoscience which underlie their inaccurate understanding of evolutionary concepts.

5.9 Conclusion

In sum, the student participants in this study tended not to hold a strong position when evaluating a level of acceptance of evolution but rather hold intermediate levels of acceptance. Apart from those who were unsure about evolution, those who accepted it tended to have some reservations, and those

who rejected it tended to reject only some parts of the theory of evolution, not all. In addition, these different levels of acceptance were found to be associated with a range of justifications which relate to either science or religion as a cognitive authority. Those accepting evolution tended to rely on science as a cognitive authority or refusing religion as a cognitive authority; whereas, those having reservations about, unsure or rejecting evolution tended to rely on religion as a cognitive authority or refusing science as a cognitive authority. This study shows that, in fact, students consider similar aspects of the theory of evolution when making their justification for the levels of acceptance of evolution. However, they are different in their interpretation of the similar aspects. While those accepting the theory evolution made their justification through aspects of the nature of science, acceptance of scientific claims or faith in science, those not accepting evolution made their justification through pseudo-nature of science, rejection of scientific claims or mistrust of science. In addition, the study shows that the most common justifications among students are related to nature of science and pseudo-nature of science.

I suggest that the aim of the development of instructional approaches should be to focus more on the distinction between the nature of science and pseudo nature of science. I believe that appropriate understanding of the nature of science would enhance student acceptance of evolution with justified understanding well as helping them to be able to perceive the differences between science and religion and will help them to avoid inappropriately conflating scientific knowledge with religious beliefs.

Chapter 6

Student positions of the origin of life and biodiversity

This third empirical chapter continues the interest of the previous chapter in student acceptance of the theory of evolution. However, the focus now specifically moves to explicit consideration of how students perceive the relationship between biological evolution and biblical creation. It begins with a review of literature on various classifications of positions of the origin of life and biodiversity based on both scientific and religious explanations and then provides a preferred classification which combines a range of positions proposed in other studies. Then, it reviews empirical studies on student changes in the understandings of evolution, followed by the justification of this research and specific questions and the development of the research tool used here. This is named the *Creation-Evolution Self-Identification Inventory (CESII)*, and includes eight *positions* representing different degrees of the incorporation of religious accounts into scientific explanations regarding the origin of life and biodiversity, as well as a Likert-format question designed to gauge reasons for changes in position.

A Wilcoxon signed-rank test comparing positions before and after a course on evolution revealed that there were significant shifts towards increasing acceptance of evolution among the students. These positive shifts were self-reported to be influenced by changes in understanding of the evidence for evolution as well as ways for relating science and religion, rather than religious beliefs. This study shows that the tool is sufficiently effective to detect relatively subtle shifts in positions among high school students. In addition, it draws attention to the importance of evolution instruction focusing on the evidence for evolution and the relationship between science and religion, as these might be able to assist students in viewing evolution in more positive ways without changing in their religious beliefs.

6.1 Why study positions on the origin of life and biodiversity

In this section, I justify my interest in studying student positions on the origins of life and biodiversity. Scott (2005) explains that many people, at least in the United States, are likely to perceive the relationship between the biblical accounts of divine creation and the scientific explanation of evolutionary theory as a dichotomy, with “evolutionists” on one side and “creationists” on the other. Rather unfortunately, this impression appears to lead many to conclude that because “creationists” believe in God, “evolutionists” have to be atheists (Scott, 2005). In fact, like the relationship between science and religion discussed in Chapter 4, the actual relationship between evolution and creation is also complicated and can be much more complex than this black-and-white relationship suggests. Collins (2006) points out that there are various forms of belief among those who accept the creationist accounts as well as variations between those accepting evolutionary theory.

Smith (2010a) argues that an acceptable aim of evolution education is to support learners in reaching a point where evolutionary theory is accepted as a scientifically valid explanation of the diversity of life forms, without obliging them to change their religious beliefs. It is therefore important to explicitly identify a range of positions of the relationship between evolution and creation in order for learners as well as teachers to be aware that, in fact, there are positions in which evolution is accepted but that do not require rejecting religious beliefs in a Creator God, such as *theistic evolution*, *deistic evolution* and *agnostic evolution*. In addition, according to Lederman (2002), a key goal of science education is the development of a sophisticated personal epistemology about scientific knowledge. Therefore, identifying a range of positions of the relationship between evolution and creation as a “spectrum”, including the least scientifically sophisticated position at one end and the most scientifically sophisticated at the other, would help teachers and educators to trace the level of scientific sophistication that their students have developed. The next section presents such a spectrum of positions of the relationship between evolution and creation in the context of the question on the origin of life and biodiversity. In short, I will call them *positions of the origin of life and biodiversity* throughout.

The tool used for assessing student positions on the spectrum of the relationship between evolution and creation could be used to provide teachers with information about which positions students choose. Knowing student positions is important particularly for the development of teaching approaches as well as planning for learning materials. Teachers could gain ideas relating how students tend to integrate their religious beliefs in divine creation in their understanding of evolution. Knowing the rough number of students who reject evolution would be also very helpful so that teachers might be able to prepare to respond to them more effectively. In addition, using the tool to assess student positions on the spectrum would allow teachers to trace how their students have changed their understanding of evolution or have developed their scientific sophistication in relation to religious beliefs throughout the course of study.

6.2 Positions of the origin of life and biodiversity

As discussed in the previous chapter, a number of empirical studies adopt a binary or a ternary classification in order to categorise different levels of student acceptance of evolution. Researchers generally classify student positions of evolution in three broad groups - those accepting, being unsure and rejecting evolution. This common classification is not only used for ease (e.g. to create categorical variables) of student views in quantitative studies adopting a deductive approach in which response categories are usually pre-defined (e.g. Donnelly et al., 2009, Ingram and Nelson, 2006, Woods and Scharmann, 2001), but also for identifying qualitatively different positions using an inductive protocol (e.g. Clores and Limjap, 2006, Hokayem and BouJaoude, 2008).

Although I acknowledge that this classification is useful for a variety of research purposes, and in fact Chapter 5 focuses on this in particular, I argue that some concerns still arise from it. First, by presenting this classification of the relationship between biological evolution and biblical creation to students, they are likely to be misled that they can only either accept or reject the theory of evolution. As Winslow et al. (2011) point out, average pupils are unaware of other positions of the relationship between scientific explanations of evolution and religious beliefs of divine creation; and thus they tend to perceive only a

black-and-white relationship between the two. Allowing them to select only one of three choices according to the pre-formulated responses would limit their consideration of alternative views. Ironically, therefore, research that uses this kind of scheme in investigating acceptance may even be contributing to this problem.

Second, responses to evolution need to be considered in conjunction with those of the “cousin worldview” in the form of religious perspectives. As also explained elsewhere in this thesis, adopting a reductionist approach to separate scientific from other worldviews, especially religion, may not reflect actual ways that students perceive the world. Although science teachers may choose to avoid considering other worldviews in their instruction because they are perceived as non-scientific, Hokayem and BouJaoude (2008) suggest that it is very important to consider student worldviews as they contribute to different ways in which students engage with learning materials. In addition, responses to evolution need to be considered in conjunction with other relevant scientific theories, especially abiogenesis (i.e. explanations of the origin of life). Unlike scientists, Rice et al. (2010) point out that average members of the public and school students may not actually see the distinction between the origin of the first living thing (abiogenesis) and the origin of species from ancestral species (evolution); but rather, they use both to construct their understanding of the biological world in which a great variety of life forms exist (biodiversity). Therefore, excluding abiogenesis when investigating viewpoints on biological evolution might provide a deficient picture of the complex phenomenon of student learning about evolution.

Having in mind the links between evolution and religious perspectives as well as abiogenesis, I searched the literature for the categorisations of positions in which these elements are included. I found that Scott (2005), Brem et al. (2003), Verhey (2005) and Collins (2006) provide solid grounds for further development. Therefore, I compared and synthesised these categorisations and developed a single framework which includes possible positions on the origin of life and biodiversity, covering explanations from both religious and scientific arenas. The following paragraphs discuss the framework in greater detail.

A range of categorisations of ways of viewing the relationship between creation and evolution can be found in the literature. The comparison and synthesis of these classifications are shown in Table 6.1, showing the correspondence between these. Taking a theoretical approach, Scott (2005) proposes a continuum of positions of the relationship between creationist perspectives and scientific explanations of evolutionary theory, ranging from literal creation, young earth creationism, old earth creationism (i.e. gap creationism, day-age creationism and progressive creationism), theistic evolutionism, agnostic evolutionism, to materialistic evolutionism. However, there are two positions proposed in Scott (2005)'s classification that are not included in this review (i.e. flat eartherism and geocentrism) because these are concerned with the origin of the universe which belong to physics, rather than the origin of life and biodiversity. Along similar lines, Collins (2006) discusses the relationship between biblical interpretations regarding divine creation and biological evolution, categorising these into five different positions composing of creationism, theistic evolution, deistic evolution, agnostic evolution and atheistic evolution.

Taking a more empirical approach, Verhey (2003) adopts a classification of positions proposed by Nelson's (1986) which is similar to those proposed by Scott (2005), containing six positions: Christian Literalist, Young Earth Creationist, Progressive Creationist/Intelligent Design, Theistic Evolutionist, Nontheistic Evolutionist and Atheistic Evolutionist position. Although the use of this classification was successful among university students in the US, no actual statements representing the positions used in his data collection are provided in Verhey (2003). This therefore makes research replication impossible.

Another classification is proposed by Brem et al. (2003) which is also successfully used among students in the US. This classification consists of five positions which represent strong creationist (no evolution), human-only creationist (humans do not evolve, but others do), interventionist (divine intervention in evolution), theistic evolutionist (divine initiation of evolution) and nontheistic evolutionist positions (no divine actions in evolution). This classification not only provides a range of positions of the origin of life and

biodiversity, it also draws clear distinctions between these positions. In addition, the actual statements of these positions used in empirical work are provided in Brem et al. (2003).

Positions proposed in this study	Scott (2005)	Brem et al. (2003)	Verhey (2005)	Collins (2006)
<i>Literal creationism</i>	Young earth creationism	Strong creationist	Literal creationist	Creationism
<i>Higher genera created</i>	-	-	Young earth creationist ¹⁵	-
<i>Humans only created</i>	-	Human-only creationist		-
<i>Progressive creation</i>	Old earth creationism	-	Progressive creationism/ Intelligent design	-
<i>Theistic evolution</i>	Theistic evolutionism	Interventionist	-	Theistic evolution
<i>Deistic evolution</i>		Theistic evolutionist	Theistic evolutionist	Deistic evolution
<i>Agnostic evolution</i>	Methodological naturalism	-	Nontheistic evolutionist	Agnostic evolution
<i>Atheistic evolution</i>	Philosophical naturalism	Nontheistic evolution	Atheistic evolutionist	Atheistic evolution

Table 6.1: Positions on the origin of life and biodiversity in the literature and in this study

Based on these four classifications, eight positions are proposed comprising *literal creationism*, *higher genera (of animals) created*, *humans only created*, *progressive creationism*, *theistic evolution*, *deistic evolution*, *agnostic*

¹⁵ The term Young Earth Creationist used by Verhey (2005) is explained in the light that some evolution may have happened, but only at the biological family level which is differently from the use of Scott (2005) who describes Young Earth Creationist in a more literal fashion that organisms existing today appear in the form that they were created since the beginning (no evolution). This description is rather closely aligned with Literal Creationist used by Verhey (2005).

evolution and *atheistic evolution* as shown in Table 6.1. In order to make it clear throughout this thesis, these proposed positions are shown in italics. Five positions are directly taken from the categorical statements proposed by Brem et al. (2003) because of their simplicity, success in empirical use and availability. The additional three positions are drawn from the other listed sources and rewritten to make them sound consonant with Brem et al. (2003)'s linguistic style. All actual statements used in the study reported here are shown in Table 6.2. This chapter presents the positions as a spectrum (see Figure 6.1) in which the most literal sense of interpretation of religious texts (*literal creationism*) is on the far left and the most scientific sense on the far right (*atheistic evolution*). These positions are now discussed in turn.

6.2.1 Creationism

There are four positions that can be broadly classified in the group of creationism in which abiogenesis is fully rejected, whereas evolution is conditionally accepted in certain species. However, there are minor variations in terms of the strictness of the rejection of evolution within this group. Therefore, four different positions of creationism are proposed. First, *literal creationism* refers to the strongest sense of literal interpretation of Genesis that allows no room for evolution to explain the emergence of any life forms. Its proponents claim that God alone created everything in the first place (Brem et al., 2003, Collins, 2006, Scott, 2005). A looser form of creationism is adopted by some students in the study of Samarapungavan and Wiers (1997), and this is called *higher genera created*. Those holding this position believe that God created biological genera described in Genesis: sea animals, birds, land animals and humans. Therefore, divine creation is directly involved in these higher taxonomical genera of organisms, while the evolution of other life forms is open to debate. Another position is *humans only created* in which its sense of literalness is somewhat weaker, viewing that evolution might happen in other forms of life but not human beings since it is written in Genesis that only human beings were created in the image of God (Brem et al., 2003, Collins, 2006, Scott, 2005).

A special form of creationism is known as *progressive creationism*. Its proponents fully embrace a range of cosmological and geological evidence in its explanation. To some degree, its proponents accept scientific evidence relating to the origins. However, they interpret it in the light of their creationist perspectives. For example, they argue that it is not through abiogenesis but God's initiation that the first biological molecules and single celled organism emerged. In addition, they reject the idea that different "kinds" of organism naturally evolved from one another through natural selection but believe that God carried on his creation by forming them sequentially (i.e. God first created single celled, then created the more complex, then multi-cellular organisms, then higher taxonomical animals and humans). To those holding this view, fossil records are accepted as the narration of the history of God's creative work. Scott (2005) argues that because this position admits a range of modern scientific theories (i.e. cosmology and geology), it can be perceived to be less literal than the previous positions. It should be noted here that Verhey (2005) interchangeably calls this view *intelligent design* (ID).

6.2.2 Divine evolution

The other two positions, *theistic evolution* and *deistic evolution*, can be grouped in *divine evolution* according to which both abiogenesis and evolution are accepted as divinely led processes. However, the two positions are identified depending on different views on divine intervention. As Peters (2007) explains, both theism and deism admits that there is a God Creator. However, while the God of theism is active and intervenes in (all) natural processes across all time, the God of deism is thought of as having set up the world and left things to run through natural laws since this creation. Collins (2006) refers to the former as the "God of Abraham" and the latter as the "God of Einstein". However, he refers to both as theistic evolution. The terms used are also confusing in Brem et al. (2003)'s study as they call the former *interventionist evolution* and the latter *theistic evolution*. Thus, to make it clear throughout this chapter, as well as recommendation for consistency for any further studies, I rely on the terms and definitions used by Peters (2007) which are *theistic evolution* (evolution occurred under God's providence) and *deistic evolution* (evolution was set in motion by God). At a superficial level, these two positions

might not be different scientifically but rather theologically. Therefore, the justification of their level of sophistication is drawn from the degree of literalness. Since deistic evolution is less literal than theistic evolution, I consider that it is more scientifically sophisticated on the spectrum¹⁶.

Positions	Descriptions
<i>Literal creationism</i>	All forms of life were first brought into being by a deity in more or less their present form at the same time.
<i>Higher genera created</i>	Some forms of life evolved from earlier forms created by a deity, but higher taxonomical species such as reptiles, birds and mammals were created in more or less their present form.
<i>Humans only created</i>	Some forms of life evolved from earlier forms created by a deity, but human beings were created in more or less their present form.
<i>Progressive creationism</i>	All forms of life were gradually created over time by a deity in more or less their present form.
<i>Theistic evolution</i>	All forms of life evolved from earlier forms, but a deity intervenes from time to time to shape or override the evolutionary processes.
<i>Deistic evolution</i>	All forms of life evolved from earlier forms, but life and evolution were first set in motion by a deity and then left running without any additional intervention.
<i>Agnostic evolution</i>	Life emerged from non-living particles and then all current forms evolved from these earlier forms. A deity may exist, however, this is out of scope of evolutionary theory.
<i>Atheistic evolution</i>	Life emerged from non-living particles and then all current forms evolved from these earlier forms. No deity has ever played any role in the evolution of life on Earth.

Table 6.2: Positions of the origin of life and biodiversity, with descriptions used in the empirical study described here

¹⁶ I am aware that the relationship with science of the theistic and deistic evolution positions could be distinguished. Specifically, the deist God no longer interacts with the world, the only lasting “trace” of his existence is the universe itself, which by definition follows “laws” that are both divine and natural. In other words, if science establishes a law (or theory), there is no way of distinguishing between divine and natural. In contrast, the theist God works in a world of natural laws but has the power to “distort” or override these. Therefore, at least in principle, we have to assume that he is scientifically consistent or rational or in some way not arbitrary in order to make predictions about what his “trace” in the world might look like. However, this distinction is made in principle rather than in practice. To put it into practice, I am still convinced that distinguishing them by the degree of literalness is useful.

6.2.3 Nontheistic evolution

This third group, *nontheistic evolution*, consists of two positions i.e. *agnostic evolution* and *atheistic evolution* in which both abiogenesis and evolution are fully embraced. However, they are different in terms of the use of science to justify other belief systems including religious beliefs. According to *agnostic evolution*, one cannot know whether God plays any role in evolution as the theory of evolution is built through scientific methods that search for only naturalistic explanations. Although the same acknowledgement of the limits of science may exist among those subscribing to divine evolution positions, agnosticism argues that it is impossible to know whether evolution is a divinely driven or natural process and hold no beliefs; both theists and deists do have faith and believe that God has a role in evolutionary processes, even if they believe that this cannot be demonstrated scientifically. Therefore, its proponents adopt scientific explanations to explain natural events regarding both the origins of life and of species without referring to either the role or the existence of God (Brem et al., 2003, Scott, 2005). In contrast, *atheistic evolution* holds that science can explain everything in the universe including the origins, and thus (or that) no God exists (Peters, 2007).

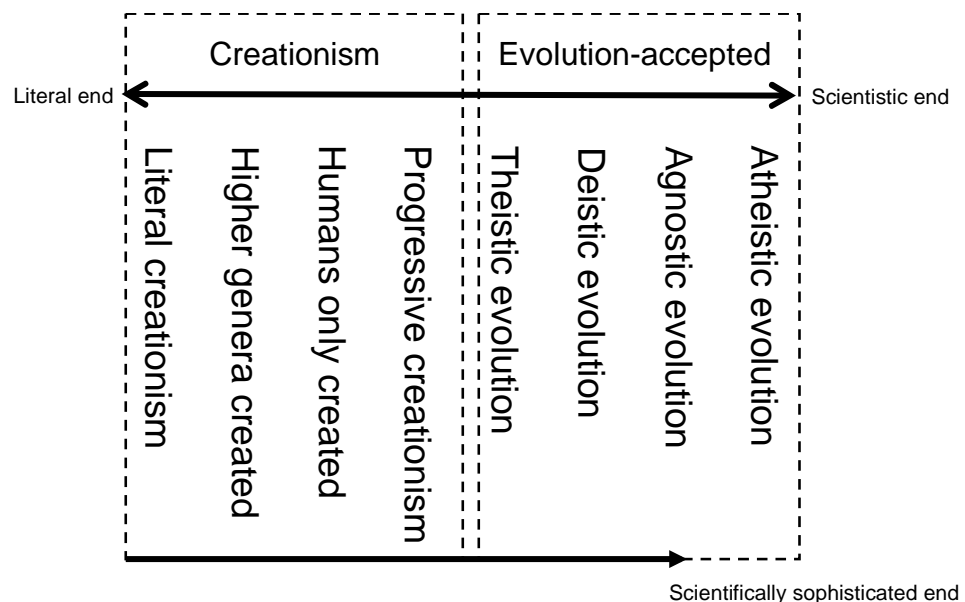


Figure 6.1: The spectrum of positions of the origin of life and biodiversity

Many scientists and philosophers have critically argued that agnosticism is more scientifically sophisticated than atheism because no scientific means are able to prove or disprove the existence of supernatural beings and scientific questions are limited to naturalistic events examined by empirical investigations (Collins, 2006; Peters, 2007). However, to make our spectrum harmonious, atheistic evolution is located at the very right as it is radically opposed to literal creationism, although it might well be thought of as less scientific than agnostic evolution (see Figure 6.1). In this paper, it is stated clearly when discussion focuses on levels of *scientific sophistication* in which atheistic evolution is excluded from the analysis; otherwise, analysis refers to the full range of the eight positions.

The spectrum focuses on levels of sophistication in individual understandings of evolutionary processes and their relationship with concepts of God. As a result, the ordering of positions is according to their scientific sophistication as opposed to scriptural literalness. Although fascinating, the notion of religious sophistication - and its validity as desirable - is inherently problematic, and full discussion of this point is beyond the scope of the present thesis. Nonetheless, one could consider scriptural *interpretations* such as theistic and/or deistic evolution as more or less sophisticated (e.g. at the very least in a similar way to interpretations of secular texts).

Less problematically, the range of religious beliefs is vast, and sophistication in understanding the subtle distinctions between these is key to the endeavours of religious philosophers and theologians. Although the spectrum described here covers a range of concepts of God and his relationship with the nature, the philosophical literature contains a much broader range of conceptions (Peters 2007). For example, this spectrum fails to capture concepts more closely aligned with pantheism (i.e. the belief that all things are divine). One might argue that a pantheist or panentheist (i.e. the belief that all things exist within God's being) would not distinguish so sharply between the initial creation event and continuing evolutionary process, considering instead that evolution forms part of the work of creation. Of course, individuals may use the terminology differently, such that a self-identified theist might in fact hold views closer to those

described here as pantheistic or panentheistic. However, these understandings do not appear in evolution education literature. For this reason, it was believed that such fine distinctions would be unlikely to arise among high school students without formal philosophical or theological training literature and thus they are not included in this spectrum. However, further exploration of these distinctions with students of this age would certainly constitute an interesting extension to this work.

6.3 Changes in positions of the origin of life and biodiversity

In his widely cited book, *the Language of God: a Scientist Presents Evidence for Belief*, Francis Collins, a Christian scientist, thoroughly explains his own journey of beliefs regarding science and faith (Collins, 2006). Having been brought up in a freethinking family within a Christian country, he had a vague concept of God in his childhood. This sense of spirituality went undeveloped when he entered university where he was exposed to naturalistic and mathematical explanations of the ordered universe through majoring in Chemistry. At this stage, he identified himself as an agnostic. After graduation, he continued his PhD study in physical chemistry when his belief continuously shifted to atheism as he was convinced that physical principles could explain everything in the universe. Changing his area of study to medicine, he was fascinated by the complexity of life and biochemical molecules; and later changed his belief to theism and now maintains a theistic evolution position.

This personal scenario is consistent with constructivist accounts that one's conceptions can be altered throughout life through either assimilating or accommodating new information to the previously constructed store of knowledge as one continues to learn and experiences new things (Demastes et al, 1995; Evans, 2008). Moving from Collins' testimony to a larger group of individuals, there is reason to believe that during a certain period of evolution education, students may reconstruct their conceptual understanding of the biological world in particular ways as a consequence of the interactions between scientific knowledge and personal worldviews, including religious ones. One major question of interest in this chapter therefore is whether student positions

of the relationship between religious and scientific understandings in relation to the question of the origin of life and biodiversity differ after taking a biology course on evolution, and the relationships between those positions before and after studying evolution explicitly.

6.4 Previous studies on student changes in positions

Studies show that learning of science often involves process of shifting from general misconceptions to more scientifically sophisticated perspectives (Demastes et al., 1996; Evans, 2008; Sinatra et al., 2008). Assuming that *agnostic evolution* represents the most scientifically sophisticated position (as argued above), I wished to test the hypothesis that student development is in the direction of increasing scientific sophistication. For example, some individuals might start from the least scientific position, *literal creationism* and move forward to the intermediate positions - *higher genera created*, *humans only created*, *progressive creationism*, *theistic evolution* and/or *deistic evolution* until they reach the most scientifically sophisticated position, *agnostic evolution*. However, some might end up (or transition through) the most radical position, *atheistic evolution*, as found in one stage of Collins' journey. Theoretically, the same principle can be applied to initially atheistic students, and the hypothesis tested that their view may become "softer", moving "backward" to *agnostic evolution* or one of the other positions. I now review existing evidence relating to these hypotheses.

McKeachie et al. (2002) explore how college students in the US undertaking an introductory course on biology accept the theory of evolution in relation to the creationist account of divine creation by using a survey protocol. Data collection took place in two stages: first at the beginning and then at the end of the term. Regarding the data from the first survey, the researchers divide the 60 participants into four groups: 10 rejected evolution, 22 were unsure about it, 17 accepted both evolution and the Bible, and 11 accepted evolution as fact. Although this categorisation is different from what is focused on here, student changes in position can be inferred. After the second stage of data collection, the researchers note that positions have changed among nine students. More

specifically, one student who initially rejected and another one who was unsure about evolution came to the reconciliatory position at the end. In addition, four of those being unsure and three holding the reconciliatory position came to accept evolution as fact. Although the authors claim that the “changes were toward belief in evolution” at the end of the course (p. 190), it is not clear that such a solid claim can be made from these nine cases. It leaves some curiosity for sceptical readers and quantitative researchers to question whether this occurred by chance. Also, although these data appear to show a shift in the direction of more positive attitudes towards evolution acceptance among the students, the researchers do not test statistical significance of the shift.

Winslow et al. (2011) explore changes in student positions¹⁷ of the relationship between the theory of evolution and their religious beliefs. Using in-depth interviews conducted twice with 15 undergraduates or new graduates from a US Christian university majoring in biology. Their main findings reveal that 13 students had held a *literal creationism* position, one a *human only created position* (Tiffany), and one a *theistic evolution* position (Diana) as their childhood beliefs. However, at the end of their study, while Diana’s position remained unchanged, 11 literal creationists had changed their belief to *theistic evolution*, one remained unchanged and Ashley was shown to hold a position of *progressive creationism* with some elements of the *theistic evolution*. In addition, the researchers discuss that Tiffany had come to accept *theistic evolution*; however, she still held some elements of *progressive creationism*. Applying these findings of Winslow et al. (2011) to the spectrum of the positions on the origin of life and biodiversity, it is possible to assume that the Tiffany has moved forwards two steps from *humans only created* to *theistic evolution*, the 11 literal creationist students have moved forwards 4 steps to *theistic evolution*, and Ashley has moved at least three steps towards *theistic evolution*. Overall,

¹⁷ Position names used by Winslow et al. (2011) are slightly different from the position names proposed in the spectrum. However, to minimise confusion regarding the different names, I replaced those names used by Winslow et al. (2011) with the ones currently proposed here, without changing any definitions of the positions.

changes are therefore towards positions associated with greater acceptance of biological evolution.

Winslow et al. (2011)'s study broadens the current understanding in many ways. Firstly, it strengthens the assumption as well as the claims from the previous work (McKeachie et al., 2002) that student beliefs about the relationship between evolution and religious beliefs can change towards more reconciliatory position(s) - primarily *theistic evolution* in this particular study. In addition, it hints at the process of changes. Like the 11 former literal creationists, Tiffany was also continuing to reformulate her belief towards *theistic evolution*. However, at the time of the study, she was not yet fully successful; and therefore a mixture of elements between *progressive creationism* and *theistic evolution* were found from her verbal expressions. If this interpretation was true, it may be that *progressive creationism* might be an intermediate phase required for some literal creationists to take off their "creationist hat" and put on an "evolutionist hat" instead. Therefore, a further investigation is needed in order to clarify this by extending to a larger sample. In addition, Winslow et al. (2011) also point out some factors which assist the process of student conceptual modifications in this direction as they summarise that these changes in position happen through "evaluating evidence for evolution, negotiating the literalness of Genesis, recognizing evolution as a non-salvation issue, and observing professors as Christian role models who accept evolution" - all considered in the instructional interventions used in this study (p. 1026).

Another piece of work conducted by Verhey (2005) provides a somewhat clearer pattern of how students change their positions on evolution and creation. In his quasi-experimental research design, Verhey (2005) divides the student participants attending an undergraduate level at a US university into two groups and each has two replicates. While students in the first group (n = 38) were exposed to a modified instructional approach through reading assignments and in-class discussions in which their prior conceptions (experience, knowledge and beliefs) in relation to the relationship between evolution and creation and the nature of science were explicitly considered, the second (n = 28) did not focus on such prior knowledge (different reading assignments given). At the end of the

term, the students were invited to participate in an optional survey in which the researcher provided six positions on the spectrum of the relationship between evolution and creation initially proposed by (Nelson, 1986) - Literalism, young earth creationism, progressive creationism/intelligent design, theistic evolution, non-theistic evolution, and atheistic evolution¹⁸ - for the students to choose one. Students were asked to recall the position that they had held before taking the course, together with choosing the one adopted after taking the course. The results reveal that the number of students showing a change in the positions in the first group is greater than those in the second group. More specifically, 23 students of the first group self-reported having changed their position, while only 6 of the other group did so. An interesting pattern of movement can be found among the first group. Four out of six literalists in the first group were found to change to other positions composing young earth creationism (n = 1), theistic evolution (n = 2) and atheistic evolution (n = 1). Moreover, although over half of young earth creationist students remained unchanged, some moved to progressive creationism/intelligent design, theistic evolution, or non-theistic evolution. Although, I did not try to map these changes in position to the spectrum of the positions of the origin of life and biodiversity deliberately, I would like to point out based on these findings that the students were likely to become more scientifically sophisticated as they tended to move from the more literal positions to the less. However, the challenge of this study is that none of these findings were statistically tested.

In addition to these findings, Verhey (2005)'s study also provides a method for assessing student positions of the origin of life and biodiversity and changes in positions. Verhey is aware that one might argue against the validity of his research protocol because it requires the participants to recall the position that they had held while they might be actually holding another position. However, he defends this approach by pointing to two important rationales. First, he argues that there would be no trouble for the participants to recall their former

¹⁸ I did not replace these position names originally used by Verhey (2003) because there are minor differences between these and the ones currently proposed in this chapter.

position at the end of the course which lasts only 11 weeks. Second, he argues that using the same research tool twice with the same participants could influence student positions during the course. This is due to the fact that, while completing the questionnaire, the students may become informed about some other positions that they might not have been aware of. This, of course, would make their new position after the course artificial.

While being convinced that Verhey's methodological approach is useful in terms of eliciting student positions of the origins and changes, I am aware that the quasi-experimental approach and the before-after question alone does not inform us of the reasons for the changes. More specifically, implicit in the quasi-experimental approach used in Verhey's study is the idea that one can only interpret the finding that difference between groups appears as due to the different teaching methods (i.e. one embeds student prior experiences, knowledge and beliefs associated with the relationship between evolution and creationism and the nature of science in formal learning, whereas the other does not). So, differences in shifts in position between groups are considered "due to" the intervention. However, what this does not tell us is why individuals changed their position or what it was in the teaching that caused the shifts, or whether the students themselves attributed these shifts to the teaching. Therefore, I consider that an explicit question asking students directly what reasons make them change their view would allow us to conclude this more confidently.

6.5 Reasons for student changes in the positions

In the literature to date, it is unclear what factors actually underpin student changes in the positions regarding the origin of life and evolution. However, three main reasons are found to be influential for individuals to hold a position of the origin of life and biodiversity. They are as follows.

First, Collins (2006) makes it clear to his readers that his own journey of belief has been influenced by his experiences in scientific explanations and evidence when he studied at the university levels. Taking understanding of the evidence

for evolution (an aspect of the nature of science) into consideration, Hokayem and BouJaoude (2008) also show that all students who accepted evolution in their study did so because they found its evidence convincing. In contrast, those who were uncertain and rejected the theory tended to find it unconvincing. Likewise, while 36% of those accepting evolution in Downie and Barron (2000)'s study viewed that the evidence is clear and unambiguous, 33% of those rejecting it viewed that it is rather contradictory.

Second, two empirical studies point to the important role student views of the relationship between science and religion (see Taber et al., 2011, Yasri and Mancy, 2012) in determining positions on evolution. Although their studies focus on the broader level of the relationship between science and religion, the context in which both groups of researchers focus is evolution education (i.e. the relationship between evolutionary theory and divine creation). Findings from both studies show that students can accept evolutionary theory when they perceive a form of compatibility between science and religion (e.g. in the form of agnostic evolution or divine evolution), or when they perceive science as highly authoritative in explaining the natural world (e.g. in the form of atheistic evolution). In contrast, those rejecting evolution tended to hold an incompatible view in which religious knowledge is understood to be more credible than scientific knowledge (and held positions such as literal creationism or higher genera created).

Apart from these two reasons for taking a particular position - the persuasive nature of evidence and understandings of the relationship between science and religion - Downie and Barron (2000) also report in their study that the majority of those rejecting evolution were religious (either Muslim or Christian). In addition, they show that those rejecting evolution were significantly more likely to have a religious belief compared to those accepting evolution. Factors related to religious beliefs are also discussed by a number of authors. For example, based on a survey using a questionnaire containing three open-ended questions for undergraduate students majoring Biology in Lebanon to provide written responses, Dagher and BouJaoude (1997) showed that almost half of the participants holding Islamic faith provided arguments against evolution, claiming

that it is antithetical and harmful to their beliefs and values of life. In addition, Brem et al. (2003) report that accepting evolution was understood to be socially destructive because it is linked to perceptions of a sense of purpose of life and belief in spiritual life which, in contrast, are provided in religious perspectives.

Therefore, this study focuses particularly on these three reasons which may contribute to student changes in position of the origin of life and biodiversity: (1) understanding of the evidence for evolution, (2) the perceived relationship between science and religion, and (3) religious beliefs; these three factors thus represent scientific, philosophical and religious reasons, respectively.

6.6 Rationale and purpose of this study

According to the review of the literature, although simplistic studies using categories composing of “accept evolution”, “accept creation” or “accept both” such as McKeachie et al. (2002) have tended to show only very small numbers of students changing position, the qualitative work of Winslow et al. (2011) suggests that changes in position are more common. One possible explanation of this apparent paradox is that changes are too subtle to be identified in the studies using only two or three categories. The work of Verhey (2005) supports this explanation, although his work lacks appropriate statistical analysis and misses out some positions as discussed below.

As discussed, the previous studies leave a number of unclear answers to the question about student positions about the origin of life and evolution. First, two of the reviewed studies (i.e. Brem et al., 2003; Verhey, 2005) show an attempt to include a range of positions regarding the origin of life and the origin of species in their instruments. However, they miss out some positions which are referred to in other studies. Specifically, Brem et al. (2003) did not include *higher animals created*, *progressive creationism* and *atheistic evolution*. Verhey (2005) leaves out *deistic evolution* and conflates *humans only created* with *higher genera created*. Second, although some of the studies show a positive direction of student changes in their position towards scientifically sophisticated positions (e.g. Verhey, 2005; Winslow et al., 2011; McKeachie et al., 2002),

there is no statistical evidence for changes using subjects who have been measured at two time points (i.e. before and after). In addition, although the two studies explain possible reasons for student changes in positions (Winslow et al., 2011; Verhey 2005), reasons for changes are not directly given by students themselves, but drawn out as inferences from the instructional inventions used in the studies. Finally, the relationship between the magnitude of change in positions and number of reasons is unexplored.

Therefore, the particular aims of this study are to fill these gaps by investigating whether and how high school students change their positions of the origin of life and biodiversity on the spectrum proposed (Figure 6.1), and examining the reasons for change as well as their association with the magnitude of change in positions. A new research tool called the *Creation-Evolution Self-Identification Inventory (CESII)*, which covers a full range of positions for assessing student perceptions, was therefore developed. Moreover, in this tool, the statements compose both beliefs about the origin of life (abiogenesis) and the origin of life forms (evolution). In addition, the study includes a question which directly asks students why they have changed their positions in order to draw clearer conclusions about reasons influencing the changes. Three possible reasons are provided in the tool - changes in understanding of the evidence for evolution, changes in understandings of the relationship between science and religion, and changes in religious beliefs. The aim is not to suggest that these are the only “inducers”; however, it aims to provide initial knowledge for further in-depth studies. Specific research questions are:

1. What is the distribution of positions on the origins of life and biodiversity held by high school students attending a Christian school in Thailand?
2. Is there a statistically significant change in positions among M6 students before and after undertaking evolution lessons and if so, what are the patterns of shifts?
3. What are self-reported reasons for student changes in their views regarding the origin of life and evolution?

4. Is there a statistical association between the magnitude of change in positions and the self-reported reasons?

6.7 Research method

6.7.1 Student and school participants

While the detail of the recruitment of the school and student participants is explained in Chapter 3, this section provides relevant information in relation to school contexts that is useful for making sense of the findings. Before this study was conducted, as a part of my MSc dissertation, I participated in activities in the school in order to gain better understanding about the school environment, as well as interviewing two biology teachers who have been responsible for teaching a compulsory biology course including evolutionary theory to all students undertaking a science and mathematics programme in the school.

Grades	Mean age	Number of participants			
		Buddhists	Christians	Others	Total
M4	15.68	80 (69.6%)	30 (26.0%)	5 (4.4%)	115 (100%)
M5	16.64	63 (72.4%)	23 (26.4%)	1 (1.1%)	87 (100%)
M6	17.58	75 (60.0%)	42 (33.6%)	8 (6.4%)	125 (100%)

Table 6.3: Characteristics of student sample

These preliminary activities demonstrated that among high school students (M4, M5 and M6), those undertaking a biology course on evolution are all enrolled in M6 level (comparable to A2 in the English or S6 in the Scottish system). Each class takes 3 hours per week and runs for 3 months from November to January, including both lectures and laboratory exercises. In the meantime, all students in this school have to attend a religious study course for one hour per week. Based on the religious denomination of the school, Protestantism, Christian doctrines including creation narratives are taught to all students. This means that the students are more or less familiar with the ideas of divine creation. While M6 students (N = 125) were the target population in this particular

chapter, M4 (N = 115) and M5 (N = 87) students were also included in order to show general tendency of student positions of the origin of life and evolution. These students mainly hold Buddhism or Christianity as their religious orientations as seen in Table 6.3.

Focusing on the instructional approach used by the two teachers, my previous research showed that both of them adopted a perspective which aligns with the *contrast* view proposed in Yasri and Mancy (2012). More specifically, at the beginning of the course, the teachers introduce to their students the differences between science and religion (Christianity), focusing on their different ways of acquiring knowledge of the world: while science deals with the physical world in which explanations are drawn from evidence and experiments that are commonly agreed by scientists in specific fields, religious knowledge concerns values and purposes of life, aiming to provide a set of teachings that can help people spiritually. However, having done this, the teachers respect that there are other ways in which science and religion can be related.

The teachers further explained that, for practical reasons, they have to limit discussions in their classrooms to learning scientific evidence and explanations of evolution, rather than philosophical issues related to evolution and faith and do not address this issue further during class time. However, the students are encouraged to discuss with them privately concerning philosophical issues that may arise during free time. After making this clarification to the students, they start their instruction by using evolutionary evidence to initiate discussions and explain how explanations can be drawn from this. In addition, while teaching the key concepts of evolution, they try to integrate these with other biological topics such as taxonomy, physiology and anatomy in order to make evolution the central theme to understanding of the biological world. When assessing student understanding, the teachers are open to any faith that acknowledges the ultimate cause of evolution and the universe; however, for the sake of the school science education, they explicitly ask the students to explain in examinations papers the proximate causes of things (i.e. evolutionary mechanisms).

6.7.2 Data collection

Relevant items in the questionnaire in the part of the *Creation-Evolution Self-Identification Inventory (CESII)* for this particular study composed of two questions: first, eight statements representing positions of the origin of life and evolution in relation to religious beliefs, with two columns for the students to choose their actual view(s) both before and after undertaking the course and including an “other” position for them to describe any alternative view; and second, three statements asking the reasons for their changes with a blank space for them to fill in other possible reasons (the full questions are provided in Appendix C). While the first task requires the students to select one answer, the second asks students to rank from 1 (strongly disagree) to 5 (strongly agree) depending on their levels of agreement with the statements providing reasons for changes in positions. M6 students were asked to complete all of the tasks. However, the questionnaire given to M4 and M5 students is different as it includes only task 1 and only one column provided as these students had not studied evolution and therefore could not be expected to have “before” and “after” positions.

6.7.3 Data analysis

Descriptive statistics are used to present student positions of the origin of life and evolution. The patterns of changes in positions were assessed using a cross-tabulation of their views selected “before” and “after” taking the course. Individual changes were statistically tested by using a Wilcoxon signed-rank test (a non-parametric test used when comparing two repeated measurements on a single sample to assess whether their population mean ranks achieved before and after taking the course differ). Furthermore, the reasons for changing based on the Likert-scale statements were analysed by descriptive statistics and a Chi-square test. Finally, a statistical test of the association between the magnitude of change and the reasons were done using a Spearman correlation test (a non-parametric test used to measure of statistical dependence between two variables).

In this study, the spectrum of the relationship between evolution and creation regarding the questions of the origin of life and biodiversity can be interpreted

in two philosophically different ways. Firstly, composing the full whole range of positions, I examined the level of biblical *literalness* in which the most literal position, *literal creationism*, is located on the far left; while the least literal, *atheistic evolution*, is on the far right. Secondly, I was also interested in the level of scientific sophistication. Focusing on this, I consider *agnostic evolution* the most *sophisticated*; and thus atheistic evolution was removed from some parts of the analysis.

6.8 Findings

6.8.1 Student positions on the origin of life and biodiversity

The analysis shows that the research tool was capable of distinguishing student positions on the origin of life and biodiversity as every single position proposed in the tool was selected by student participants (see Table 6.4). It also shows that the student participants generally selected positions consistent with biological evidence. More specifically, almost 42% selected *agnostic evolution* and 21.7% *atheistic evolution*. An equal number of the students (7.7%) selected *theistic evolution* and *deistic evolution*. Only about 5% selected either *literal creationism*, *higher genera created* or *humans only created*. The smallest number (1.9%) was shown to select progressive creationism. However, 17 out of the whole sample did not choose a preferred position. Additional statements were written by 14 students. However, none of the written expressions provided an informative argument for creating an additional position.

Comparing between Christian and Buddhist students in particular (frequencies and percentages are shown in Table 6.4 and a clustered bar chart is shown in Figure 6.2), almost 40% of the Christian sample (n = 93) held one of the creationist positions especially *literal creationism* (15.1%) and *humans only created* (12.9%). About 30% of them selected one of the *divine evolution* positions and almost 27% selected *agnostic evolution*. In other words, about 57% of them selected a position in which evolution is fully accepted, while almost 40% selected a position in which evolution is rejected on the basis of literalness.

Positions	Whole sample ¹⁹	Christian sample	Buddhist sample
Literal creationism	14 (4.5%)	14 (15.1%)	0 (0%)
Higher genera created	14 (4.5%)	8 (8.6%)	5 (2.4%)
Humans only created	15 (4.8%)	12 (12.9%)	2 (1.0%)
Progressive creationism	6 (1.9%)	3 (3.2%)	2 (1.0%)
Theistic evolution	24 (7.7%)	15 (16.1%)	9 (4.3%)
Deistic evolution	24 (7.7%)	13 (14.0%)	11 (5.3%)
Agnostic evolution	131 (41.9%)	25 (26.9%)	100 (48.3%)
Atheistic evolution	68 (21.7%)	1 (1.1%)	65 (31.4%)
I don't know	17 (5.4%)	2 (2.2%)	13 (6.3%)
Total	313 (100%)	93 (100%)	207 (100%)

Table 6.4: Student positions on the origin of life and biodiversity

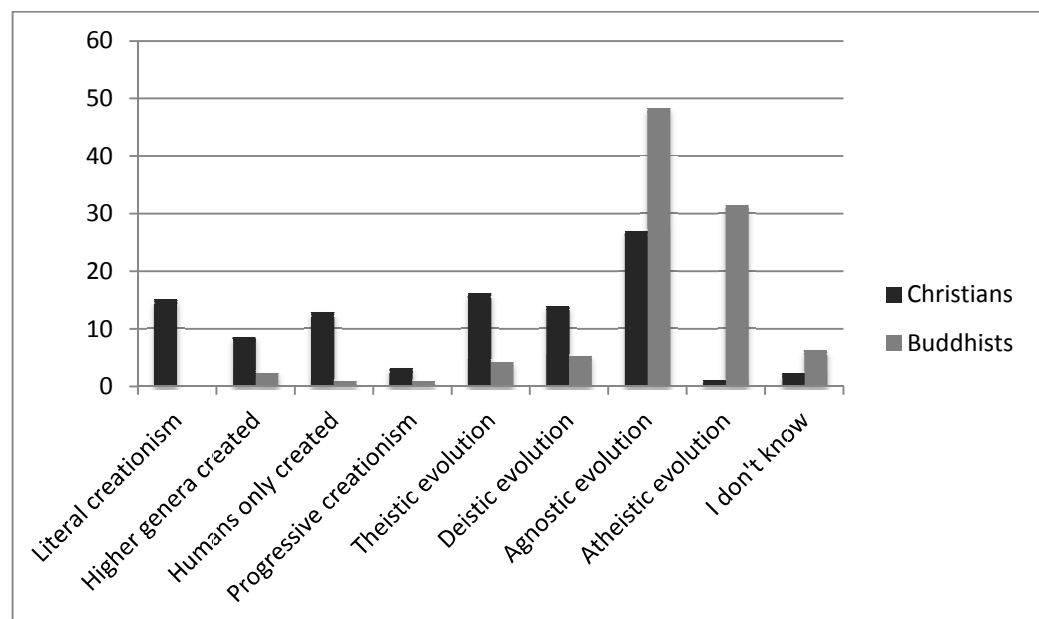


Figure 6.2: Distribution of positions on the origin of life and biodiversity, compared between Christian and Buddhist students

In contrast, almost 50% of the Buddhist students (n = 207) selected *agnostic evolution* and over 30% selected *atheistic evolution*; while about 10% chose one

¹⁹ Responses from M4, M5 and M6 students (after taking the course) are combined here

of the divine evolution positions and less than 5% chose one of the creationist positions. In other words, about 90% of them selected a position in which evolution is accepted (of which most of them accepted it non-theistically), and less than 5% of them selected a position in which evolution is rejected on the basis of literal interpretation of the Bible.

I now focus on student positions in relation to educational levels. However, student positions are grouped into three: creationist, divine evolutionist and non-theistic evolutionist positions in order to allow the conduct of Chi-square tests. This is because if the eight positions were considered separately, there would be many cells that contain less than 5 counts and these are not valid for a Chi-square test. Grouping the positions into the three broad groups as shown in Table 6.5, the analysis shows that the distribution of student positions is statistically indistinguishable among M4 and M5 students ($\chi^2 = 1.58$, $df = 5$, $p = 0.904$). While over 60% of each grade selected a non-theistic evolution position (either *agnostic evolution* or *atheistic evolution*), almost one quarter selected one of the creationist positions (either *literal creationism*, *higher genera created*, *humans only created* or *progressive creationism*). The smallest proportion among them (13.8%) chose one of the divine evolution positions (i.e. either *theistic evolution* or *deistic evolution*). This suggests that among these students who had not taken the course on evolutionary theory, the two polarised positions are generally adopted, even though they tend to prefer *non-theistic evolution* over *creationist* positions²⁰.

The adoption of two polarised positions are more evident among M6 students before they took the course on evolution. While about 38% selected one of the creationist positions, 50% selected one of the non-theistic positions. Although the ratio of those holding the creationist positions seems to be higher among M6 students before taking the course, compared to both M4 and M5 students, chi-square tests show that neither the distribution of student positions between M4 students and M6 students before taking the course ($\chi^2 = 9.74$, $df = 5$, $p = 0.083$),

²⁰ This is likely to be due to the large number of Buddhist students in the sample.

nor the distribution of student positions between M5 students and M6 students before taking the course ($\chi^2 = 9.30$, $df = 5$, $p = 0.098$) is statistically distinguishable.

Grades	Creationism	Divine evolution	Nontheistic evolution	Total
M4	26 (23.9%)	15 (13.8%)	68 (62.4%)	109 (100.0%)
M5	18 (23.4%)	9 (11.7%)	50 (64.9%)	77 (100.0%)
M6 (before)	36 (38.3%)	11 (11.70%)	47 (50.0%)	94 (100.0%)
M6 (after)	5 (4.5%)	24 (21.8%)	81 (73.6%)	110 (100.0%)

Table 6.5: Student positions of the origin of life and biodiversity in relation to grades

However, statistically different patterns of distribution of positions are seen among M6 students who had taken the course compared to M4 students ($\chi^2 = 25.74$, $df = 5$, $p = 0.0001$) and M5 students ($\chi^2 = 23.27$, $df = 5$, $p = 0.0003$), as well as the distribution of their own positions selected before taking the course ($\chi^2 = 30.86$, $df = 5$, $p = 0.0000$). The overall pattern is that almost three quarters of the M6 students chose one of the non-theistic evolution positions to explain the origins after taking the course on evolution. In addition, 22% selected one of the divine evolution views and less than 5% selected one of the creationist positions. This shows that almost all of the M6 students (95%) chose a position in which evolutionary theory is accepted after taking the course.

6.8.2 Student changes in positions of the origin of life and biodiversity

Now only responses from M6 students are considered. Based on Table 6.6 it is interesting to see that a high proportion - over 76% - of the M6 participants changed their position of the origin of life and biodiversity, while 29 out of the whole sample (23.3%) did not change position after undertaking the course. Among those not changing position, almost all held a non-religious position: 63.2% maintained an *agnostic evolution* position and 32.1% retained an *atheistic evolution* position. Among those changing position, seven were found to change

their view from one of the specific positions to *I don't know*, and two to *Others*, but these did not form an additional position because their written responses are not relevant to a description of the origin of life and biodiversity.

Focusing only on those who reported a change within the eight positions on the spectrum proposed (N = 96 out of 125), before undertaking the course, the students held a range of positions: 35 *creationism*, 11 *progressive creationism*, 3 *theistic evolution*, 8 *deistic evolution*, 19 *agnostic evolution*, 28 *atheistic evolution* positions and the rest chose *I don't know*. Like M4 and M5 students, it appears that a relatively larger number of students held the two extreme positions at the beginning of the course. Interestingly, after the course, there were subtle but common changes in their positions. Specifically, among the initial *literal creationism* students, only two of them (8.3%) remained in the same stance, while the others had moved to more scientifically sophisticated positions including *theistic evolution* (25.0%), *deistic evolution* (20.8%) and *agnostic evolution* (29.2%). One individual (4.2%) moved to *agnostic evolution*. A similar pattern is found among the *progressive creationism* students as they all shifted to either one of the divine evolution positions (45.5%) or *agnostic evolution* (54.5%) by the end of the course.

Almost all of the divine evolution students have moved towards the right of the spectrum, indicating generally greater acceptance of evolution. More specifically, three *theistic evolution* students finished the course holding three different positions: *deistic evolution*, *agnostic evolution* and *atheistic evolution* positions. Five *deistic evolution* students shifted to *agnostic evolution* and two to *atheistic evolution*, whereas one moved to the left to *higher genera created*. Furthermore, there was an exchange between the holders of the *agnostic evolution* and *atheistic evolution* positions. Specifically, while about 20% of the *agnostic evolution* students changed to *atheistic evolution* and 63.2% remained the same, a substantially large number of the *atheist evolution* students (53.6%) became less scientific as they chose *agnostic evolution* at the end of their study.

Since it is impossible to locate those who selected the *I don't know* position either before or after taking the course in the spectrum, seven respondents were further removed when carrying out statistical tests on the trend of change. A Wilcoxon signed-rank test was conducted to compare student shifts in positions about the origin of life and biodiversity before and after taking the course across the spectrum of the eight positions of the origin of life and biodiversity. There was a significant difference in student positions between the two points (mean = 1.47, $t(86) = 5.75$, $p = 0.000$). This statistic reveals that the changes in positions within individual students after taking the course were statistically significant and the direction is towards the right end of the spectrum about 1.47 steps from where they started, indicating generally greater acceptance of evolution.

In order to explicitly examine how individual students have moved within the spectrum of scientific sophistication from *literal creationism* to *agnostic evolution*, those who selected *atheistic evolution* either before or after taking the course were excluded. The same statistic as above was calculated which shows that there was also a significant difference in students positions during the two points (mean = 2.37, $t(53) = 7.57$, $p = 0.000$). This result suggests that individual students not holding an *atheistic evolution* position either at the start or the end tend to move towards more scientifically sophisticated positions from where they started by about 2.37 steps. This number is larger than the one in the previous calculation because the mean number of steps in the right-hand direction is to some extent compensated by those shifting from *atheist evolution* to *agnostic evolution* (i.e. left) in the previous one.

Additional Wilcoxon signed-rank tests were carried out in order to compare the trend shifts between Christian and Buddhist students. Focusing on the Christian subsample, there was a significant difference in their positions across the spectrum between before and after taking the course (mean rank = 2.63, $t(38) = 4.419$, $p = 0.000$). This statistic reveals that the shifts within individual students after taking the course were statistically significant and the direction is towards the right end of the spectrum by about 2.63 steps from where they started which indicates generally greater acceptance of evolution. In addition, there

was a significant difference in student positions in relation to scientific sophistication between before and after taking the course (mean rank = 3.00, $t(35) = 4.719$, $p = 0.000$). This result suggests that the changes in positions of within individual students after taking the course were statistically significant and the direction is towards more scientifically sophisticated positions by 3 steps from where they started.

Focusing on the Buddhist sample, the analysis shows that there was no significant difference in their positions across the spectrum between before and after taking the course (mean rank = 0.65, $t(43) = 1.815$, $p = 0.070$). However, there was a significant difference in their positions regarding scientific sophistication between before and after taking the course (mean = 0.47, $t(15) = 1.999$, $p = 0.046$). This statistic reveals that the changes in position for individual students after taking the course were statistically significant and the direction is towards more scientifically sophisticated positions by about 0.47 steps from where they started.

In sum, the analysis suggests that over a period of 3 months of study, students, and particularly Christians, tended to have changed their positions towards the right-hand end of the spectrum, indicating greater acceptance of evolution, as well as towards more scientifically sophisticated positions. From the whole sample, almost 70% changed their positions within the spectrum. Almost half of those taking the creationist positions at the beginning of the course changed to the divine evolution positions at the end. Over 80% of those taking the divine evolution positions at the beginning changed to the non-theistic evolutionist positions at the end, while about 87% of those taking non-theistic evolutionist positions remained within this non-theistic realm.

			Positions taken after the course								Total	
			Creationism			Divine evolution		Non-theistic evolution		I don't know		Others
			Literal creation	Higher general created	Humans only created	Theistic evolution	Deistic evolution	Agnostic evolution	Atheistic evolution			
Positions taken before the course	Creationism	Literal creation	2	1	1	6	5	7	1	1		24
			8.3%	4.2%	4.2%	25.0%	20.8%	29.2%	4.2%	4.2%		100.0%
		Humans only created					1					1
							100.0%					100.0%
	Progressive creationism				1	4	6				11	
					9.1%	36.4%	54.5%				100.0%	
	Divine evolution	Theistic evolution					1	1	1			3
							33.3%	33.3%	33.3%			100.0%
		Deistic evolution		1				5	2			8
				12.5%				62.5%	25.0%			100.0%
	Non-theistic evolution	Agnostic evolution						12	4	3		19
								63.2%	21.1%	15.8%		100.0%
		Atheistic evolution				1		15	9	3		28
						3.6%		53.6%	32.1%	10.7%		100.0%
	I don't know					3	2	8	10	6	2	31
						9.7%	6.5%	25.8%	32.3%	19.4%	6.5%	100.0%
Total			2	2	1	11	13	54	27	13	2	125
			1.6%	1.6%	.8%	8.8%	10.4%	43.2%	21.6%	10.4%	1.6%	100.0%

Table 6.6: Student changes in positions of the relationship between creationist and evolutionist explanations regarding the origin of life and biodiversity (positions taken before the course are in rows; and positions taken after in columns)

6.8.3 Student reasons for changes in position

The previous analysis revealed that there were significant shifts towards increasing acceptance of evolution among the students. I now explore different reasons that contribute to these shifts. This analysis shows that these positive shifts were self-reported to be influenced by changes in understanding of the evidence for evolution as well as ways of relating science and religion, rather than religious beliefs.

Samples	Reasons for changing	Strongly disagree	Disagree	Not sure	Agree	Strongly agree	D:A
All (N=96)	Understanding of evidence	0.0%	5.2%	33.3%	54.2%	7.3%	1:12
	Science-religion relationship	1.0%	6.3%	44.8%	37.5%	10.4%	1:7
	Religious beliefs	16.7%	10.4%	37.5%	30.2%	5.2%	1:1
Christian (N=35)	Understanding of evidence	0.0%	5.7%	40.0%	48.6%	5.7%	1:10
	Science-religion relationship	0.0%	2.9%	45.7%	45.7%	5.7%	1:18
	Religious beliefs	40.0%	14.3%	11.4%	31.4%	2.9%	2:1
Buddhist (N=57)	Understanding of evidence	0.0%	5.3%	28.1%	57.9%	8.8%	1:13
	Science-religion relationship	1.8%	8.8%	43.9%	31.6%	14.0%	1:4
	Religious beliefs	3.5%	8.8%	52.6%	28.1%	7.0%	1:3

Table 6.7: Student reasons for changing in the positions

More specifically, the descriptive statistics shown in Table 6.7 show that a relatively higher number of the students tended to disagree or strongly disagree that their change in position resulted from changing their religious beliefs (27.1%) compared to understanding of the evidence for evolution (5.2%) and the relationship between science and religion (7.3%). Furthermore, while over 60% and almost 50% of the participants tended to agree that their changes resulted from changes in understanding of the evidence and the relationship between

science and religion, respectively, 35% agreed that these were due to changes in their religious beliefs.

The far right column representing ratios between student disagreement and agreement (D:A) given provides a clearer trend for this result. Among the whole sample, for every 12 students who agreed that their changes have been influenced by the understanding of the evidence, and for every seven who agreed that their changes had been influenced by changes in their understanding of the relationship between science and religion, there was one who disagreed with either of these. This becomes more distinctive when focusing on the Christian sample, where the highest ratio was found in student views towards the impact of the relationship between science and religion (1:18), followed by the understanding of the evidence (1:10); in contrast, for every student who agreed with religious alteration, there were two who disagreed with this.

A slightly different result was found among Buddhist students who appear to show stronger agreement with the statement relating to changes in their understanding of the evidence (1:13). However, the ratios are more equivalent when concerning changes in religious beliefs (1:3) and in the relationship between science and religion (1:4). It can be interpreted that both understanding of the evidence for evolution and the relationship between science and religion are important factors for Christian students to reformulate their positions about the origin of life and biodiversity. In contrast, it is more likely that Buddhist students rely only on the understanding of the evidence. However, changing in religious beliefs is perceived to have less impact on their changes in the positions.

6.8.4 Correlations of magnitude of change and reasons for changing

While the first analysis reveals that students have changed their positions of the origin of life and biodiversity, the second analysis further shows that student changes in position are associated with changes in understanding of the evidence for evolution as well as ways for relating science and religion, rather than religious beliefs. It is therefore interesting to follow up these findings by

asking whether the magnitudes of changes are statistically related to the level of agreement with each reason for changes, and the number of reasons for changes or not.

The magnitude of change referred to here means the number of positions that students have shifted. For example, a student who took literal creationism before taking the course and then has moved to agnostic evolution at the end of his study obtains a +6 score according to the eight positions proposed. Focusing on the whole range of the positions, a Spearman's rank order correlation was calculated to determine the relationship between 87 students' magnitude of change and their perceived level of agreement given to each reason for changing. It reveals that there was a moderate negative correlation between the magnitude of change and level of agreement with changing in religious beliefs ($r_s(85) = -0.307$, $p = 0.014$). However, a significant correlation was not found between the magnitude of change and the rest of the reasons. This suggests that the larger the shift towards the less literal positions, the less students agree that this was influenced by changing in religious beliefs.

Turning to the levels of scientific sophistication along the spectrum, those selecting atheistic evolution either at the beginning or the end are now excluded. The same statistic was calculated to examine the correlation between 54 students' magnitude of change and their level of agreement with each of the three reasons. The same result was found. While neither understanding of the evidence nor the relationship was found to be statistically related to the magnitude of change, there was a moderate negative relationship only between changing in religious beliefs and the magnitude of change ($r_s(52) = -0.327$, $p = 0.039$). This also suggests that the larger the change towards more scientifically sophisticated positions, the less they agree that their religious beliefs have changed.

Furthermore, the correlation between the magnitude of change and the number of reasons was examined. Seventy students selected either "agree" or "strongly agree" for at least one of the three reasons. Specifically, 26 changed their positions as the result of changing one reason, 19 attributed their change to

different combinations of two reasons and 25 changed because of the three reasons (see Table 6.8). A Spearman's rank order correlation test showed that there was no significant relationship between the two either on the spectrum of the "degrees of literalness" or "scientific sophistication". This suggests that it is not the number of the reasons but the reasons themselves that matter.

		Positions after taking the course					Total		
		Creationism	Divine evolution	Agnostic evolution	Atheistic evolution	Unknown			
Positions before taking course	1.1 Changing in understanding of the evidence (n = 18)							Single reasons (N = 26)	
	Creationism	-	5	2	-	-	7		
	Divine evolution	-	1	-	2	-	3		
	Agnostic evolution	-	-	-	2	-	2		
	Atheistic evolution	-	-	1	-	-	1		
	Unknown	-	2	1	2	-	5		
	1.2 Changing in relationship between science and religion (n = 7)								
	Creationism	-	1	3	-	-	4		
	Divine evolution	-	-	1	-	-	1		
	Atheistic evolution	-	-	1	-	-	1		
	Unknown	-	-	1	-	-	1		
	1.3 Changing in religious beliefs (n = 1)								
	Unknown	-	-	-	1	-	1		
	2.1 Changing in understanding and religious beliefs (n = 5)							Double reasons (N = 19)	
	Creationism	-	-	1	1	-	2		
	Divine evolution	-	-	2	-	-	2		
	Unknown	-	-	-	1	-	1		
	2.2 Changing in understanding and relationship (n = 11)								
	Creationism	1	1	1	-	-	3		
	Agnostic evolution	-	-	-	1	-	1		
	Atheistic evolution	-	-	3	-	1	4		
	Unknown	-	-	2	1	-	3		
	2.3 Changing in relationship and religious beliefs (n = 3)								
	Creationism	-	1	2	-	-	3		
	3.1 Changing in understanding, relationship and religious beliefs (N = 25)								Triple reasons
	Creationism	-	4	1	-	-	5		
Divine evolution	-	-	1	-	-	1			
Agnostic evolution	-	-	-	1	2	3			
Atheistic evolution	-	1	6	-	1	8			
Unknown	-	3	3	2	-	8			

Table 6.8: Student changes in position in relation to the number of reasons

6.9 Discussion

6.9.1 Distribution of student positions on the origin of life and biodiversity

In order to respond to the first research question concerning the distribution of student positions on the origin of life and biodiversity, the analysis shows that

the overall distribution shows that the highest proportion of the participants selected *agnostic evolution*, followed by *atheistic evolution*, *divine evolution* and *creationism* positions, accordingly. However, when the distribution is considered in conjunction with educational levels, two distinct patterns emerge. First, the analysis shows that student positions tended to be polarised (i.e. either creationist or nontheistic evolutionist positions were selected) among M4 and M5 students as well as M6 students before taking the course on biological evolution. However, second, after taking the course, the pattern of distribution of positions among the M6 students is similar to the overall pattern that is the majority of them selected the nontheistic evolutionist positions, followed by divine evolutionist and creationist positions, accordingly.

When the distribution of positions is considered in relation to religious beliefs by comparing between Christian and Buddhist students, two different patterns also emerge. First, among the Christian students, the majority of them selected the creationist positions, followed by the *divine evolutionist* and *agnostic evolution* positions, accordingly. In contrast, second, the distribution of positions among the Buddhist students is similar to the overall pattern. However, a substantially large number of them selected the nontheistic evolutionist positions, followed by a small number of those holding the divine evolutionist positions and much lower number of those holding the creationist positions²¹.

Based on these findings, this chapter contributes to the research community of evolution education in many ways. First, it shows that every position of the origin of life and biodiversity in the spectrum can actually be held by students, indicating that the inclusion of the eight positions is empirically valid. Also, it shows that the previous studies adopting different positions of the origin of life and biodiversity such as Brem et al. (2003) and Verhey (2005) missed out some positions, particularly the variation within the creationist positions (i.e. *literal*

²¹ In future work, it may be helpful to revise the descriptors of religious belief as one possible explanation of this finding is that students who selected 'Buddhist' - perhaps on the basis of family religion - were actually Christian in terms of their own faith. Alternatively, it may be that these students do not make a meaningful distinction between Buddhism and Christianity, or that they merge the two belief sets in some way.

creationism, *higher genera created*, *humans only created* and *progressive creationism*). Also, in the widely used continuum of the relationship between evolution and creation proposed by Scott (2005), the distinction between *literal creationism*, *higher genera created* and *humans only created* is not concerned, but they seem to be combined in *young earth creationism*.

Second, this is the first study that shows the distribution of positions of the origin of life and biodiversity among Buddhist students. No clear explanation is given to explain why this group of sample is missing in the existing literature; on the other hand, a large number of studies have been conducted within Christian and Islamic settings. It is possible that people may expect to observe greater diversity of responses among respondents within the monotheistic contexts as a consequence of interactions between scientific understanding of evolution and their religious traditions. However, this study uncovers that while a large number of the Buddhist participants selected *agnostic evolution* and *atheistic evolution* which are more or less consistent with their religious beliefs (i.e. nontheistic traditions), some of them (about 15%) expressed some sort of theistic beliefs through the selection of one of the divine evolutionist, as well as creationist positions. One possible explanation could be the influence of the Christian setting where they study. However, this needs to be further explored.

Last but not least, although many include Christian samples in their studies and present their positions of the origins in some way, this study still provides new information. It shows that high school Christian students, at least in this study, held a range of the positions on the origin of life and biodiversity which imply different degrees that they incorporate scientific understanding of evolutionary theory to their religious beliefs, varying from the most literal to the more scientific positions. In fact, they prefer the *divine evolutionist* and *agnostic evolutionist* to the *creationist* positions.

6.9.2 Student changes in position of the origin of life and biodiversity

The answer to the second research question on student changes in position on the origin of life and biodiversity is that over a semester of evolution education over 70% of the student participants changed their positions on the origin of life

and biodiversity and the direction of change is towards more scientifically sophisticated positions (or less literal positions), particularly *agnostic evolution*. The proportion of students changing position is perhaps surprising, especially given that other work has often failed to detect much evidence of change (Downie and Barron, 2000), at least when considering acceptance as the relevant construct. The evidence presented here appears to demonstrate that changes can occur at high frequency, but perhaps that these take place at a finer level of granularity than those considered in earlier work (acceptance versus rejection). However, this finding may also be dependent on the student sample under consideration, and this suggestion would need to be tested empirically in other populations.

In particular, among those who initially adopted one the *creationist* positions, many held more scientifically sophisticated positions after undertaking the course (most changed to be the *theistic evolution*, *deistic evolution* or *agnostic evolution* positions). Theoretically, this indicates that they have come to adopt a (at least partially) scientific worldview when considering the question of the origin of life and biodiversity, although most of them remain theistic. Empirically, this study statistically strengthens Verhey (2005)'s result in relation to the shift pattern of those holding creationist positions which is towards the less literal positions.

Winslow et al. (2011) explain that Christian students (at least in the US) tend to be brought up hearing that evolution contradicts the Bible and only creationist narratives can explain the origins. Some may have heard about non-scientific statements against evolution which make them misunderstand and reject evolution before studying it in the classroom. However, if they come to learn that they can accept both religious beliefs in God and evolution, their attitudes towards evolution are likely to be more positive and this may drive them to lean towards reconciliatory positions. On the basis of this study, although many of the students who initially took a creationist position became less literal and more scientifically sophisticated at the end of the study, it appears to be difficult or even impossible for them to abandon the theistic zone. As it is shown, although the creationist students changed their positions towards the more

scientifically sophisticated dimension, their new positions remain within one of the divine evolution positions, perhaps to explain the ultimate cause, but not for explaining the mechanisms of the natural phenomena. More radically, some of them arrive at the position in which evolutionary events and the origins are perceived to be located in a scientific domain and thus this is kept away from religious belief, according to *agnostic evolution*.

Focusing on those initially holding one of the *divine evolutionist* positions in this study, the analysis shows that 10 out of 11 changed their position to the right end of the spectrum, varying from 1 to 3 steps. Five out of them selected *agnostic evolution* at the end of the course. In contrast, five out of seven of those initially subscribing *theistic evolution* in Verhey (2005)'s study did not change their position. I assume that the detectable shift among the *divine evolutionist* students in this study may result from the clear distinction between *theistic evolution* and *deistic evolution* in the spectrum which is absent in Verhey (2005)'s classification. In fact, one third of those initially subscribing *theistic evolution* in this study moved to *deistic evolution*. It might be possible that there are some minor changes in student understandings of the *theistic evolution* position in Verhey (2005)'s study after taking the course; however the research tool used might not be sensitive enough to elicit these changes.

However, the similarity between this study and Verhey (2005)'s study is backward shifts of those holding the *divine evolutionist* positions. Specifically, one out of eight students holding *deistic evolution* in this study changed their position to *higher genera created*, and two out of seven students in Verhey (2005)'s study changed from *theistic evolution* to *progressive creationism*. Although the number of those expressing the backward shifts in these two studies is small, the pattern is evident. This is because the *deistic evolution* position in this study and the *theistic evolution* in Verhey (2005)'s study are the first positions where a backward shift begins to be observable. Both are similar in the sense of being a transitional position before reaching *agnostic evolution*. In other words, they are the turning point from the theistic to the nontheistic zones. This point might be a critical stage for some to decide to leave a theistic worldview in order to be genuinely scientific or to be non-literal when dealing

with evolution education. However, some may fail to do so and decide to “turn back” to one of the more literal positions such as *progressive creationism* according to the two students of Verhey (2005) and *higher genera created* according the student in this study. Given the small number of students in this group, no solid claim can be drawn from this study. Further investigations are required to understand this observation of backward shifts at the left border of *agnostic evolution*.

Another interesting pattern of student change in position is found among those initially holding the *non-theistic evolutionist* positions. Specifically, the majority of those initially subscribing to *atheistic evolution* (15 out of 24) moved towards *agnostic evolution* (one step backward in the spectrum), meaning that they have become less scientistically extreme or more scientifically sophisticated. This appears to be similar to the finding of Verhey (2005) in terms of the backward direction of the shift. However, the student in Verhey (2005)’s study (one out of three) changed from *atheistic evolution* to *progressive creationism* instead. Again, this highlights the significance of studies on backward shifts of student positions in future studies. Turning back to the result from this study, it shows that the development of scientific sophistication among those initially taking *atheistic evolution* appears in a positive direction and is similar to the pattern of change anecdotally described by Collins (2006). As Collins (2006) points out, careful scientists will not over-expand their scientific knowledge to make claims about things beyond science and in particular the issue of the existence of God as may be done by some holding *atheistic evolution*.

The final discussion about student changes in position is concerned with the responses from those initially holding *agnostic evolution*. This study shows that about 63% of those initially taking an *agnostic evolution* position did not change their position after taking the course. This is similar to the result from Verhey (2005) which shows that none of those initially taking *agnostic evolution* (n = 9) changed their position at the end of the study. The confidence in holding the position among these students implies that the students may not encounter challenges which effectively lead them to see the need for changing their

position. In addition, learning about evolutionary theory may fit well with the worldview that they adopt to make sense of things around them, and thus over the period of the study, they remained unchanged. Therefore, based on the fact that those initially holding *agnostic evolution* did not change their position, and a large number of the creationist, divine evolutionist and atheistic students tend to move towards this position, I argue that *agnostic evolution* is an appropriate position for both learners and educators to consider because it allows individuals to maintain the status of scientific knowledge, evidence and methods, while avoiding threats to religious disciplines.

6.9.3 Student reasons for changing position

In order to respond to the third research question on student reasons for changing position, the analysis shows that there are two potential reasons underpinning change: understanding the evidence for evolution and changes in understanding of the relationship between science and religion. However, the participants tended to disagree that their shifts were due to changes in religious beliefs. In fact, the larger the change towards more scientifically sophisticated positions, as well as the less literal positions, the less they agree that their religious beliefs have changed. In addition, the analysis shows that it is not the number of the reasons but the reasons themselves that matter, thus answering the fourth research question. Therefore, based on these findings, students in this sample attribute changes in position on the origin of life and biodiversity to scientific reasons in relation to understanding of evidence for evolutionary theory and the philosophical reasons concerning the relationship between science and religion, but not to changes in religious beliefs.

Scientifically, it is not unusual for average high school students to hold some misconceptions about evolutionary theory and in particular misunderstanding about its explanations and evidence before coming to science classes. For example, students misunderstood that evolution explains how humans have evolved from monkeys (Yasri and Mancy, 2012); and may claim that evolution contains weak aspects because it lacks good supporting evidence (Hokayem and BouJaoude, 2008). However, learning how evolutionary theory has been constructed through scientifically valid evidence may enable the naïve learners

to perceive evolution in more sophisticated directions, leading to greater open-mindedness to learn and accept evolution. This may be because students come to understand what science (or evolution) is and how it works, which is the main focus of teaching the nature of science. This knowledge helps them to distinguish between science and non-science. More specifically, it gives them a relatively good understanding that evolutionary theory is an attempt to explain the natural causes of the emergence of different forms of organisms based on scientific approaches and available evidence; and therefore, it neither includes God in its realm of explanations nor specifically excludes God.

Philosophically, the student participants in the study reported here were introduced by their biology teachers to a religiously neutral way for relating science and religion at the very beginning of their course. In this approach, religion is perceived as a subjective means to acquire knowledge related to the spiritual life and morality; whereas science is an objective means to uncover the mechanisms of the physical world. This position corresponds to the *contrast* view described by Yasri and Mancy (2012). Although it is recognised that there are a range of positions for relating science and religion (Yasri and Mancy, 2012), Haught (1995) asserts that this contrast approach is the “safest” for viewing the relationship and the most practical for science education (Ladine, 2009). Roth (1997) proposes that students who consider that both science and religion are socially constructed and each attempts to provide knowledge for only its own traditional and cultural domains, tend not to be trapped by conflicts between science and religion because they can separate different social discourses. By adopting the *contrast* view, students may be able to gain better understandings of how the two disciplines are differently constructed; and thus they can reconcile scientific with religious knowledge when learning about biological evolution. However, from the data presented here, it cannot be concluded that all students have taken the view of the relationship as introduced by their teachers. If this were to be true, there should have been no students selecting divine evolution (especially *theistic evolution*) as science and religion are not theoretically separate from each other in this particular stance. In fact, some student participants in this study selected *theistic evolution* at the end of the course. This suggests that many of the students might adopt either *coalescence*

(science and religion are the same knowledge which leads them see the handiwork of the divine through the lens of scientific eyes) or *complementary* (science and religion are considered two different aspects but together make the picture of the single reality more complete) suggested by Yasri and Mancy (2012).

Importantly, the findings of this study inform us that students do not attribute changes in position to changes in religious beliefs. This provides confirmation of the claim that religious students can learn and accept evolution without threatening their religious beliefs. Therefore, misguided fears by evolution rejecters can be relieved. Taken together, the findings of this study suggest that students can remain religiously autonomous after taking the biology course which deals specifically with scientific explanations and the philosophical concern of the appropriate ways to relate science and religion. I therefore agree with Ladine (2009, p. 391) who argues that “if evolution is taught as science and that it can be accepted without giving up belief in God, some students will come to accept that evolution does not violate their faith and begin to accept evolution (p. 391).”

Finally, the study shows that the newly developed tool for assessing student positions of the origin of life and biodiversity reflecting different degrees to which scientific and religious understanding are incorporated is appropriate to detect student changes, including subtle changes between adjacent positions. It is recommended for those who are interested in this topic to replicate this study in different contexts. Also, further investigations about reasons for changing in the positions are needed. A number of additional questions arise from this work. For example, it would be helpful to know what specific kinds of evidence students find convincing, and what particular examples help them make the most sense about evolutionary events and mechanisms. Also, it would be useful to see to what extent views on the relationship between science and religion are consistent with student positions.

6.10 Conclusion

In sum, this study reveals that students in this sample tended to hold strong positions of the origin of life and biodiversity (creationist and atheistic positions) before taking a course on evolution. However, it shows that there were significant shifts towards increasing acceptance of evolution among the participants. These positive shifts were self-reported to be influenced by changes in understanding of the evidence for evolution as well as ways for relating science and religion, rather than religious beliefs. In addition, it shows that it is not the number of the reasons but the reasons themselves that contribute to changes in position.

These main findings lead to practical aspects of educational implication. If one agrees with some science educators that the aim of evolution instruction is for students to understand the scientific concepts related to the theory, as well as to accept it as currently valid scientific explanations of the emergence of biodiversity, without threatening personal religious beliefs (Smith, 2010b, Smith, 2010a), then this study suggests some ways in which to work towards this aim. In particular, it may be effective to use a *contrast* approach which makes a clear distinction between the nature of religious and scientific explanations and focuses particularly on the evidence for evolution which allows the students to learn how the scientific ideas are constructed. This enables students to understand that evolution does explain how different forms of life come into being without having to be concerned that these things should make them question the existence of God. This instructional approach used did lead to more scientifically acceptable understanding even when final position did not correspond to *contrast*.

The study also provides evidence on possible changes in position. For example, it appears almost impossible (very rare) for creationist students to both theoretically and practically cross the border to atheistic evolution; therefore, attempts to drive them to the atheistic evolution position becomes impossible, and indeed, there is no reason to do so. What teachers can do is to introduce to them other possible positions where evolution is accepted and belief in God

remains intact (i.e. deistic or agnostic evolution). Indeed, this is not to “brainwash” students from having a religious belief to “worshipping” science, but to foster in them the intellectual development towards scientifically sophisticated thinking.

I conclude that the responsibility of science teachers may not be limited to presenting evolution scientifically, but also dealing with theological and philosophical issues brought up by individual students. This extra task cannot be considered unnecessary as ignoring student worldviews might exclude some students from science rather than engaging them; and this would leave the main aim unachieved. Teachers, therefore, should be understanding and patient as suggested by Smith (2010b). This study, however, encourages them that their labours are not in vain because through time and scientific environments, students’ misconceptions can be improved towards more scientifically sophistication. In addition, it draws attention to the importance of evolution instruction focusing on the evidence for evolution and the relationship between science and religion, as these might be able to assist students in viewing evolution in more positive ways without changing in their religious beliefs

My final comment is made to the usefulness of the *Creation-Evolution Self-Identification Inventory (CESII)* used in this study. The study shows that the tool is effective in detecting shifts in positions among high school students. It is also capable of assessing reasons contributing to student changes in position. I hope that researchers will choose to use this tool to investigate student positions of the origin of life and biodiversity in other settings, age groups, religious traditions and educational levels. I am also open for other researchers who might disagree with my rationale after Verhey (2005) which defends for the benefit and practicality of asking students to identify earlier positions at the end of the course, rather than testing twice. However, the analysis of the contrast between M6 and the earlier grades is consistent with the findings of the before-after positions of M6 students, lending additional support to the validity of this claim. It would be helpful and interesting to know how findings would be if this research tool is used twice (before and after a particular course).

Chapter 7

Student misconceptions of biological evolution

According to the findings from Chapter 6, high school students hold a range of different positions on the origin of life and biodiversity. These embody particular understandings of biological evolution, but do so at an aggregate level. The present chapter considers student understandings of particular aspects of biological evolution from the perspective of misconceptions. Indeed, although lists of misconceptions and possible categories have been proposed, individual misconceptions have not been categorised systematically. Furthermore, the relative frequency of these misconceptions, overall and among individuals holding different positions, has never been investigated. This final empirical chapter therefore explores these issues in greater detail. I begin by synthesising existing categorisation schemes for misconceptions and categorise each misconception within the synthesised scheme. The aim of this study is then twofold. First, it aims to highlight common and specific misconceptions about biological evolution. Second, it aims to investigate associations between misconceptions and positions (grouped as creationist, divine evolutionist and non-theistic evolutionist).

The chapter begins with a review of fundamental concepts of biological evolution relevant for high school students. This is followed by the discussion of two taxonomies of misconceptions identified from the literature. These are synthesised and used to categorise individual misconceptions listed in the literature. Specifically, misconceptions about biological evolution are systematically classified into five groups: common sense-based, content-based, NOS-based (misconceptions related to the nature of science), religion-based and vernacular-based misconceptions. The next section provides the justification for the empirical aspects of this study, identifies specific research questions and describes the research methodology.

The findings are first presented in the form of descriptive statistics relating to the number of misconceptions held by students overall, and in the three groups. In a second section, I present the common misconceptions and compare these between groups. Finally, I consider the overall distribution of misconceptions.

The findings reported in this chapter suggest that students holding different positions on the origin of life and biodiversity tend to conceive biological evolution in subtly different ways. Biology teachers can gain benefit from knowing what positions are held by their students as this should help them to support students and address specific misconceptions more effectively.

7.1 Fundamental concepts of biological evolution

This section reviews fundamental concepts of biological evolution as explained by scientists and science educators. The review aims to present a standard understanding of the theory of biological evolution which is later used to compare with misconceptions about biological evolution discussed in Section 7.2, and as the conceptual framework of this chapter for the scoring system explained in Section 7.5.4.

To begin with the definition of evolution, Scott (2004, p. 23) defines the term evolution broadly as “a cumulative change through time”. She points out that there are a range of meanings of evolution including astronomical, geological, chemical and biological evolution. However, in this chapter, I limit the term evolution only to the strand of biological evolution. Wiles (2010, p. 18) defines this as the explanation for “the diversity of life on Earth [which] has arisen via descent with modification from a common ancestry” (p. 18). Scott (2004, p. 27) specifically explains that biological evolution is not the explanation of the origin of life itself but “the descent of living things from ancestors from which they differ” (p. 27). Taking her broad and specific definitions together, Scott (2004) comments that “descent with modification through time” is an effective explanation of biological evolution.

Instead of focusing on defining the term evolution, Alexander (2009) distinguishes between three main aspects of biological evolution: evolutionary

devices (i.e. DNA and genes), evolutionary mechanisms (i.e. natural selection and reproductive success) and the result of their combination in the form of macroevolution (i.e. speciation and fossils). These aspects are relevant to five core aspects of biological evolution guided by Biological Sciences Curriculum Study (2005) which are suggested as important to introduce to high school students in the US , consisting of how species evolve over periods of time, how species evolve from common ancestors, how new forms of species derive from existing species (speciation), that evolutionary processes gradually occur, and natural selection. Indeed, these are aspects originally contributed by Charles Darwin (1859) and elaborated in his book entitled *the Origin of Species by Means of Natural Selection*, but which have been developed through the advanced knowledge of genetics and molecular biology.

As a consequence of Darwin's book, the term natural selection has been widely used. Among biological scientists, this process is generally "considered to be the most powerful source of evolutionary change" (Scott, 2004, p. 34). Pongsophon (2006) points out that high students in Thailand are required to understand five sequential steps of the mechanism of natural selection: the origin of genetic variation (alterations of genetic information of inherited traits within a population), the role of genetic variation (unpredictable outcomes which can lead to either beneficial, neutral or harmful traits depending on certain environmental conditions), change in a population trait (those having traits that are beneficial in a particular environment achieve higher reproductive rates and become dominant), the role of environment (environmental conditions as selective agents), and speciation (the emergence of distinct species resulting from the accumulation of genetically isolated populations of a single species over time).

Apart from the in-depth consideration of what biological evolution means and is about, Smith (2010b) suggests that it is also important for students to understand what evolution is not; and thus he points out three essential points. First, evolution is not a discipline of faith. In other words, the science of evolution focuses on the natural world and questions relating to supernatural powers are beyond its scope. Second, like Scott (2004), Smith (2010b) argues

that biological evolution explains the origin of species from ancestral species, not the origin of the first living organisms. In other words, there are scientific distinctions between the theory that explains the origin of life (abiogenesis) and the theory that explains the origin of biodiversity of life forms (biological evolution). Third, biological evolution is emergent, not directional. Therefore, teleological thinking which concerns purposes of evolutionary events is not an aspect of consideration based on scientific perspectives. In addition, Smith (2010b) provides an extensive list of common misconceptions derived from a review of the existing literature. This list forms the basis for the study described in this chapter, and is discussed in the next section.

7.2 Misconceptions about biological evolution

Eggen and Kauchak (2004) explain that concepts can be considered as ideas that help us make sense or understand the world around us. Thus misconceptions are preconceived notions that provide some sorts of understanding but that are not in line with justified knowledge (Martin et al., 2002). Thompson and Logue (2006) note that there are possible ways for learners to develop misconceptions such as through parents (e.g. they might be confronted with questions from their children, and rather than admitting that they are unable to answer, they might give an incorrect answer), through media (e.g. learners may consult online sources of information that they perceive as “trustworthy” but they may not provide correct information), or through teachers (e.g. learners may perceive teachers as their cognitive authority, as discussed in Chapter 5 and fully accept what they explain or believe as correct information).

Therefore, using the language of misconceptions might be considered as a “bad” way of describing student conceptions through the implication that these are “wrong”, which is relatively negative and may appear judgmental. However, although judging student understandings as “right” and “wrong” may not be helpful, the working definition of misconceptions used in this study is limited to alternative frameworks or ideas about the world perceived by learners that are different from the accepted scientific ideas. Thus misconceptions are simply those ideas that contrast with accepted scientific accounts (whether or not these are factually “correct”).

A number of empirical studies have shown that students often hold misconceptions about the theory of biological evolution (see Smith (2010b)). In order for biology teachers to help their students develop a scientific understanding of biological evolution, it is important to identify which ideas about evolution constitute misconceptions (Committee on Undergraduate Science Education National Research Council, 1997a). Smith (2010b) reviews a series of misconceptions about biological evolution and the nature of science related to the theory of evolution reported in empirical studies. He presents them in five themes: those generated from personal experiences (e.g. genetic mutations are always detrimental to fitness such as those that cause cancers and physiological malfunctions), those constructed by learners based on different stages of their conceptual development of scientific reasoning (e.g. teleological thinking that evolution is function and/or purpose directed), those caused by poor science education (e.g. Lamarckian misconceptions and misunderstanding of the nature of science), those arising from misuse of everyday spoken terms (e.g. theory versus law), those related to religious claims (e.g. young earth creationist beliefs).

Mapping Smith (2010b)'s themes of misconceptions about biological evolution onto a standard classification of misconceptions about science proposed by the Committee on Undergraduate Science Education National Research Council (1997a), a similarity is found. The Committee on Undergraduate Science Education National Research Council classify misconceptions about science into five groups: *preconceived notions*, *non-scientific beliefs*, *vernacular misconceptions*, *conceptual misconceptions* and *factual misconceptions*. Although this classification is used to explain misconceptions about science in general (no examples of biological evolution are given in the original text), it can be applied to the theory of evolution and the misconceptions compiled by Smith (2010b).

7.2.1 Synthesised classification of misconceptions

In this chapter, I propose a systematic classification of identified misconceptions about biological evolution. The need for this is that no classification of misconceptions of biological evolution has been provided in the literature.

Although Smith (2010b) proposes the five themes of misconceptions, he does not explicitly and systematically classify the misconceptions themselves, and does not discuss in the main text of his paper how these themes arose. They are only shown in the summary table where the misconceptions are presented (pp. 552-553), and grouping might be for the purpose of readability. Having noted that, I consider Smith (2010b)'s themes as a very good starting point. Therefore, based on his work and the classification of misconceptions of science in general by the Committee on Undergraduate Science Education National Research Council (1997a), I propose a systematic classification of misconceptions about biological evolution and the nature of science related to the theory of evolution in Table 7.1, and the modifications of the two ways for grouping misconceptions are discussed in the following paragraphs. Then in Table 7.2 I show that I have categorised the misconceptions themselves. I acknowledge that it is difficult to find a categorisation structure and classify individual misconceptions in a way that is entirely objective or clear-cut. Nonetheless, the scheme proposed below serves as an organisational scheme for both analysis and interpretation, allowing the reader to more easily see patterns in the findings.

First, two themes presented by Smith (2010b) (i.e. *from experience misconceptions* and *self-constructed misconceptions*) are well captured by the definition of *preconceived notions* presented by the Committee on Undergraduate Science Education National Research Council (1997a), which refer to ideas constructed by individuals' common sense based on daily life activities. Because these are difficult to distinguish as they all seem to relate to the use of personal experience to construct their own knowledge of a given phenomenon, in this study, it makes more sense to combine them and they are now called *common sense* misconceptions.

Second, whereas the Committee on Undergraduate Science Education National Research Council (1997a) differentiate *conceptual misconceptions* from *factual misconceptions*, Smith (2010b) seems to combine them in the theme of *taught-and-learned misconceptions*. In this chapter, I adopt the latter work to frame the discussion on the ground of its simplicity. In fact, I consider that *conceptual misconceptions* and *factual misconceptions*, at least in the context of biological

evolution are not completely separate. The main difference between the two is the “seriousness” of misunderstanding. That is, Lamarckian understandings of evolution constitute *conceptual misconceptions* in that even if invalid, they represent relatively sophisticated ways of reasoning about the world; on the other hand, the *factual misconception* that man evolved from monkeys is a relatively simplistic claim. *Conceptual misconceptions* are recognised by the Committee on Undergraduate Science Education National Research Council (1997a) as preconceptions about particular theories that have never been replaced by accurate scientific explanations. In contrast, *factual misconceptions* are falsities held by learners which remain unchanged through time. However, the distinctions between these kinds of misconceptions seem problematic. For example, one is obliged to determine which conceptions are “simplistic” versus “sophisticated”, or to decide whether conceptions might change over time or not. These appear ill-defined and I therefore argue that these can be combined; the term used for these in this study is *content-based misconceptions*.

Smith (2012b)	Committee on Undergraduate Science Education National Research Council (1997)	This study
From-experience misconceptions	Preconceived notions	Common sense misconceptions
Self-constructed misconceptions		
Vernacular misconceptions	Vernacular misconceptions	Vernacular misconceptions
Religious misconceptions	Non-scientific beliefs	Non-scientific misconceptions
Taught-and-learned misconceptions (content)	Conceptual misconceptions	Content-based misconceptions
	Factual misconceptions	
Taught-and-learned misconceptions (NOS)	-	NOS-based misconceptions

Table 7.1: Classifications of misconceptions about biological evolution

Finally, Smith (2010b) conflates misconceptions related to contents of biological evolution with misconceptions related to the nature of science associated with evolution in his *taught-and-learned misconceptions*, although he himself explicitly notes in the summary table which misconceptions are related to the nature of science. In science education research, these two types of misconceptions are often studied separately. I therefore argue that *content-based misconceptions* and misconceptions related to the nature of science are distinct. The term adopted here for the latter is *NOS-based misconception*, where NOS stands for nature of science.

In the following subsections, misconceptions about biological evolution and the nature of science related to the theory of evolution will be reviewed according to the proposed classification. Examples used in the discussion below are drawn from Smith (2010b), as is the full list used throughout the rest of the study. The aim of the subsections below is primarily to provide the theoretical framework of the development of the research tool used in this empirical study and to illustrate its use for classifying misconceptions.

7.2.2 Common sense misconceptions

Common sense misconceptions are ideas that arise from experiences in daily life activities, according to the Committee on Undergraduate Science Education National Research Council (1997a). Learners appear to link their experiences with natural phenomena and construct their own understanding about them based on personal rationalisation. For example, Alter and Nelson (2002) point out that it is commonly understood among learners that evolution is a needs-based process and thus animals have to evolve in order to survive. Based on this misconception, many think that evolution usually occurs in a purposeful direction starting from lower taxonomical species towards higher ones (Alter and Nelson, 2002, Smith, 2010b, González Galli and Meinardi, 2011). González Galli and Meinardi (2011, p. 147) refer to these ideas as “common sense teleology”, explained as the misuse of science to explain that something exists for a particular purpose based on non-scientific ways of thinking.

Another misconception based on common sense is an argument from design. According to this argument, the orderliness apparent in the biological world, commonly referred to as the “design”, such as biochemical pathways in living cells, structural units of biochemical molecules, the complexity of organ systems, and physiological functions of living organisms, provides evidence for the existence of an intelligent designer. A classic example of this argument is taken from William Paley who compares the complexity of living things to the complexity of a watch, which is known to be designed. The teleological argument specifically made for this analogy is that just as a watch could not exist without a watchmaker, living things could not exist without an intelligent designer. However, this argument is opposed by scientists because the complexity of the biological world can be explained through random mutation and natural selection according to Neo-Darwinian evolution (Alexander, 2009). González Galli and Meinardi (2011, p. 147) argue that design-related misconceptions are an obstacle to evolution learning.

7.2.3 Content-based misconceptions

In this study, content-based misconceptions are any ideas perceived by individuals that contradict the fundamental concepts of biological evolution described in Section 7.1. Two main content-based misconceptions are related to the theory of acquired inheritance, known as Lamarckian inheritance (Pongsophon, 2006), and the relationship between evolution and the theory of abiogenesis which particularly addresses the topic of the origin of living cells (Rice et al., 2010).

Focusing on Lamarckian inheritance, Pongsophon (2006) explains that many students believe that changes in individual organisms are made by the organisms themselves and they can pass these characteristics on to their offspring. However, Gregory (2009, p. 169) explains that that physical changes that occur during an organism’s lifetime cannot be passed on to offspring. This is because the cells that are involved in reproduction (the germ line) are distinct from those that make up the rest of the body (the somatic line); only changes that affect the germ line can be passed on.

Building from this misconception, many form the idea that evolution is a needs-based process and that animals have to evolve in order to survive. For them, evolution is understood to occur in a purposeful direction starting from lower taxonomical species towards higher ones (Alter and Nelson, 2002, Smith, 2010b, González Galli and Meinardi, 2011). However, the current knowledge from population genetics explains that the perceived direction of evolution is the consequence of the reproductive success (or fitness) of populations, not physical adaptation through a need-based process of individual organisms (Stearns and Hoekstra, 2005). In small populations, drift is also an important factor determining evolutionary outcomes.

Another example of content-based misconceptions is related to the confusion between abiogenesis and evolutionary theory. When considering the term biological evolution, many appear to view it holistically as the biological history of life, starting from the origin of the first molecules of life and the first living cell, the development of multicellular organisms, to the emergence of higher taxonomical animals and human beings. In fact, scientific explanations differentiate between the processes by which life arose from non-living matter and those by which life developed into the diverse forms recognised today: the former processes are those of abiogenesis; the latter are explained by evolutionary theory. Smith (2010b, p. 542) notes that “in the strictest sense, Darwinian evolution is an explanation of the origin of species from ancestral species, not the origin of the first living thing” (p. 542).

Linking biological evolution to physics, antievolutionists argue that evolutionary events run counter the second law of thermodynamics (i.e. that there is an overall increase in the level of disorganisation in a closed system). However, on the grounds of physical sciences, Alexander (2008) argues that this objection to evolution is factually incorrect because the entropy of the whole system does increase (i.e. the sun, the source of energy, has become less organised), even though biological complexity is increasingly well organised.

	Possible misconceptions	Accurate concepts
Common sense	<ul style="list-style-type: none"> • Biological complexities are the results of intelligent design. • Evolution explains changes in individual organisms. • Organisms evolve (themselves) to meet the needs of their environment. 	<ul style="list-style-type: none"> • Biological complexities are the results of evolutionary processes. • Evolution explains changes in populations of organisms. • Evolutionary processes happen through the mechanism of natural selection.
Content-based	<ul style="list-style-type: none"> • Evolution explains the adaptation of organisms caused by environmental changes in which useful characteristics of organisms are passed on. • Evolution explains the origin of life, the first living things or the origin of species from non-living particles. • Evolution explains linear development of humans from monkeys. 	<ul style="list-style-type: none"> • Biological evolution can be described as arising from differential reproductive rates among a population of organisms. • Biological evolution is the explanation of the origin of species from pre-existing species by means of natural selection. • Biological evolution explains the origin of species from ancestral species.
NOS	<ul style="list-style-type: none"> • Evolution is not testable in the laboratory. • Evolution contains lacks valid support. • Evolution contradicts religious belief. • Evolutionary theory is based on speculation. • Macroevolution cannot be observed in the laboratory. • Scientists doubt if evolution occurs. • Science undermines religion. • Science is unchanging. • Science involves truth and certainty. • Science is totally objective. 	<ul style="list-style-type: none"> • Evolution is testable in the laboratory. • Forms of evidence support evolution • Evolutionary theory does not undermine faith. • Evolutionary theory is based on research. • Evolutionary theory is developed from factual and historical data. • Scientists fully accept evolution. • Science is limited to the natural world. • Science develops through time. • Science is tentative. • Science is based on human endeavour.
Non-science	<ul style="list-style-type: none"> • Species existing today were created in six 24-hour days or between 6000-10000 years 	<ul style="list-style-type: none"> • Species existing today have gradually developed from their early forms over millions of years.
Vernacular	<ul style="list-style-type: none"> • Biological complexities are the result of chance and randomness. • Evolution is a purposeless process or a directionless process. 	<ul style="list-style-type: none"> • Biological complexities are the results of natural section. • Evolution is a dynamic process, resulting in beneficial, neutral or harmful traits.

Table 7.2: Summary of misconceptions and fundamental concepts of biological evolution and the nature of science related to evolution, derived and simplified from Smith (2010b). This forms the framework for the scoring of the tool. However, elements in this table may relate to more than one item in the tool itself.

A few more examples of content-based misconceptions are found in empirical studies with students. Clores and Limjap (2006) report that one of their student participants believed that humans evolved from monkeys. This is also the case in Yasri and Mancy (2012)'s study. This looks like a fairly obvious sign of misconceptions about human evolution. To be more scientifically accurate, humans share a common ancestor with modern apes, like gorillas and chimpanzees. Nonetheless, it is possible that the learners involved in these studies failed to distinguish between monkeys and other apes (including our shared proto-ape ancestor with other modern apes), in which case the misunderstanding is in taxonomic vocabulary as opposed to evolutionary processes. Finally, (Nehm and Schonfeld, 2007) report that their participants believed that evolutionary theory demonstrates coexistence between humans and dinosaurs. However, Pickrell (2006) responds sarcastically to this view that "dinosaurs and people coexist only in books, movies and cartoons. The last dinosaurs - other than birds - died out dramatically about 65 million years ago, while the fossils of our earliest human ancestors are only about 6 million years old".

7.2.4 NOS-based misconceptions

Turning to misconceptions about biological evolution in relation to the nature of science, as the Biological Sciences Curriculum Study (2005) argues, scientific theories should not be studied in isolation from the ways in which the theories have been developed. Therefore, the nature of science becomes an important area of science instruction of concern to science educators (Abd-El-Khalick, 2012, Dagher and BouJaoude, 2005). Alongside the main stream of research in the generic domain of the nature of science, student perceptions of the nature of evolutionary theory in particular have been investigated. For example, Dagher and BouJaoude (2005) propose different aspects of the nature of science related to biological evolution that college biology students tend to misunderstand. First, the students sometimes consider that no "solid" evidence to validate the theory of evolution. Second, they sometimes wrongly perceive the certainty of the theory of evolution by expressing two radical views towards the degree of certainty. Some view that the theory of evolution is unchanging,

whereas others considered that it remains uncertain and will be changed. Third, some students believe that no experimental investigations can directly test macroevolution and that experiments are required for science. Fourth, they consider that the development of the theory of evolution is ambiguous as some steps of the scientific method are missing; however, no explanation is given by the students which steps these are.

7.2.5 Non-scientific misconceptions

Non-scientific misconceptions relate to different views perceived by individual learners based on external sources other than science. Smith (2010b) specifically points out that the major form of this kind of misconceptions is associated with religious beliefs. In relation to the theory of evolution, Scott (2004) classifies a range of positions in which religious beliefs are used to explain the scientific knowledge of the origin of life and biodiversity such as flat eartherism, geocentrism, young earth creationism, gap creationism, day-age creationism and progressive creationism.

While many authors argue that these creationist perspectives are misconceptions (e.g. Pongsophon, 2006, Scott, 2004, Williams, 2009), Reiss (2009a) asserts that teachers should think of these as student worldviews rather than mere misconceptions. I agree with Reiss (2009a) that religious beliefs have their own values and should not be judged as either right or wrong, especially not “en masse” in the sense of constituting misconceptions. However, I also agree with the other authors that there are a number of religious beliefs that obviously contradict scientific discoveries, and thus it is possible to consider these beliefs as misconceptions, at least from a scientific point of view. For example, the young-earth creationist claim that the world is only about 6000-10000 years old, has been shown to be factually incorrect by strong and coherent evidence in the geological sciences. However, to be explicit that there is no intention to make claims against religious beliefs in general in this study, the term used to describe this group of misconceptions is *non-scientific misconceptions*.

To elaborate a little, I consider here as misconceptions ideas that may not be ontologically false, but for which there is no evidence. For example, to claim that the world is designed might be true, but science cannot show that to be the case. Also, and perhaps more subtly, the claim that biological complexities are the results of intelligent design might be a true statement, but these complexities can be explained by science without recourse to the notion of a designer. Thus misconceptions as considered in this study are “scientific misconceptions” and include ideas that cannot or have not been demonstrated scientifically, that go beyond scientific claims.

7.2.6 Vernacular misconceptions

According to the Committee on Undergraduate Science Education National Research Council (1997a), *vernacular misconceptions* stem from the use of particular words that are understood differently between everyday life and scientific expressions. In other words, there are a number of terms that are used differently between members of the public and members of the scientific community. For example, Scott (2005) argues that, in everyday use, a “theory” means a guess. In science, a theory is not a guess, but “a logical construct of facts and hypotheses that attempts to explain a natural phenomenon” (p. 241). Therefore, saying that “evolution is just a theory” is a vernacular misconception used to reject evolution on the ground of disbelief rather than logical arguments.

Another example is given by Mead and Scott (2010) in relation to the use of terms *chance* and *randomness*. Among the scientific community, both are used in the fashion of statistical explanations. In science, the *chance* that something will happen means that it will occur according to a known probability. For example, the chance of having a child who has a type O blood from a mother having AO and a father BO alleles is one in four. *Randomness* is normally used in the sense of being governed by equal probability. For example, within a population mating system, every female gamete might be assumed to have an equal opportunity of being fertilised by every male gamete.

In contrast, the general public and students may interpret these terms differently. Mead and Scott (2010) explain that both of the terms are used non-

probabilistically among students. Generally, Mead and Scott (2010) argue that many students misuse the terms by conflating *random* with *purposelessness* and *chance* with *directionlessness*. Often, those rejecting evolution rely on these vernacular misconceptions to spread their objections to evolution. For example, they contrast the terms *chance* and *randomness* with *design* in nature (i.e. Paley's analogy of the watchmaker). In this study, although I acknowledge that students may understand the terms scientifically, I suspect that Mead and Scott (2010) may be right that, in general, students use them non-scientifically and towards rejection of evolution. Therefore, in the analysis of this study, when students answer that natural events happen by chance or randomly, their answer is counted as a vernacular misconception. However, we cannot be sure whether the underlying misconceptions occur because of the misunderstanding of scientific explanation or misuse of the terms.

7.3 Research justification and questions

Although student misconceptions about evolution and the nature of science in relation to biological evolution have been studied by a number of researchers (Dagher and BouJaoude, 2005, Foster, 2012, Gregory, 2009), and lists of misconceptions have been constructed (see above), the frequency with which these misconceptions arise has never been established in a systematic way. Furthermore, the relationship between these misconceptions and student religious beliefs has not been explored in a religiously heterogeneous sample. In particular, I am interested to know whether the most common misconceptions among students holding different beliefs about the origins of life and biodiversity are the same, or whether there are differences. This question appears not to have been addressed empirically in the literature. However, one might hypothesise that misconceptions would be more common among creationist students than divine evolutionists, and that both of these groups would hold more misconceptions than non-theistic students.

This study therefore aims to address this gap in the literature by investigating which misconceptions about biological evolution exist among students holding the different positions, and which aspects of biological evolution are conceived

similarly and differently by them. The research design and data analysis are constructed around the following specific research questions:

1. On average, how many of the previously identified list of misconceptions do students hold, both across the whole sample and in the groups based on positions on the origins of life and biodiversity?
2. Which are the most common misconceptions, both across the whole sample and in the position groups? Which group shows the highest and lowest number of common misconceptions?
3. Is the facility value of an individual item the highest in the same group for all items, or does this vary between items?

7.4 Research methods

7.4.1 Student participants

More details related to the protocol for recruiting the school and student participants, the administration of the questionnaire and ethical considerations for social sciences research involving human subject are described in Chapter 3. This section specifically presents the characteristics of the participants who form the findings of this chapter.

Three grades, called M4, M5 and M6, in an upper secondary level, attending a Christian school in Thailand took part in this survey. The invitation to take part in this study was made known to over 500 students in these three grades. However, 327 of them decided to take part. This group of students was purposively selected because they should have gained some understanding about biological evolution and formed a particular position on the origin of life and biodiversity. This expectation is on the grounds that the students have encountered a number of Christian activities and teaching related to the biblical doctrine of divine creation from the department of religious education of the school for some years. This would make those who are from non-Christian backgrounds familiar with the concept of divine creation to some degree.

In addition, they should have had acquired some level of understanding of explanations of the origin of life and biodiversity. Although only M6 students

have successfully passed a course on biological evolution, M4 and M5 students are also expected to achieve a good grounding in biology. This is due to the fact that M4 students in the school, at the time of data collection, had successfully passed a biology course on cell biology and taxonomy which elements of biological evolution are integrated. Likewise, M5 students had successfully passed a biology course on zoology in which biological evolution is introduced in the form of comparative anatomy and physiology of different taxa of animals.

Preferred positions	Frequency	Percent
Creationist	49	15.0
Divine Evolutionist	48	14.7
Non-theistic Evolutionist	199	60.9
I don't know	17	5.2
Others	14	4.3
Total	327	100.0

Table 7.3: Student participants classified by their preferred position on the origin of life and biodiversity

As they are expected to achieve a certain level of basic biological conceptions including evolution, the classification of the participants is not based on their individual examination grades. On the other hand, they are classified according to their preferred position of the origin of life and biodiversity based on the *Creation-Evolution Self-Identification Inventory (CESII)* used in Chapter 6. At a finer level, they are divided into three groups named *creationists*, *divine evolutionists* and *non-theistic evolutionists*, as shown in Table 7.3. Creationists are those who selected the positions of *literal creationism*, *higher animals created*, *only humans created* and *progressive creationism*. Divine evolutionists are those who selected the positions of *theistic evolution* and *deistic evolution*. Non-theistic evolutionists are those who selected the positions of *agnostic evolution* and *atheistic evolution*. However, in this analysis, responses from 31 participants had to be removed because the participants had not chosen a preferred position from the list or had provided an additional position which is

not possible to match with one of the existing positions (see Chapter 5 for more details).

At a broader level, these positions are combined in two different groups (theistic and scientific positions). First, divine evolutionists and non-theistic evolutionists (together called *evolutionists*) are combined in order to compare their conceptions with creationists. Second, creationists and divine evolutionists are combined (together called *theistic students*) in order to compare their conceptions with non-theistic students. These descriptions are visualised in Figure 7.1. It is important to note that creationists and non-theistic evolutionists are always distinct; whereas divine evolutionists are grouped with one of them depending on a particular purpose of analysis clearly stated in Findings.

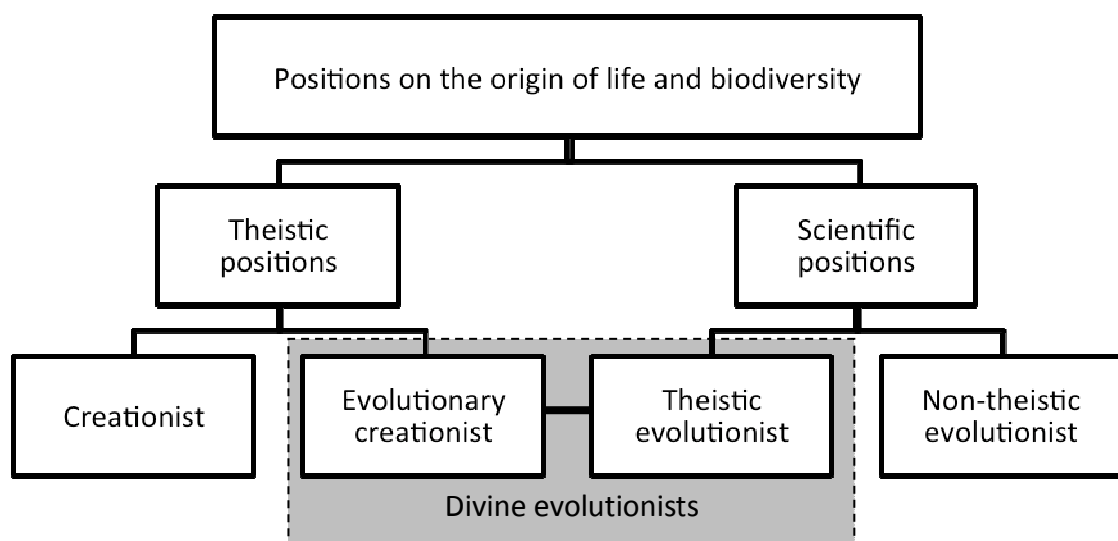


Figure 7.1: Classification of student participants

7.4.2 Data collection

In the *Measure for Understanding of Science and Evolution (MUSE)* currently developed in this study based on the list of misconceptions shown in Table 7.2 and the more complete list given in Smith (2010b). Student participants from the three grades were asked to consider 12 incomplete statements (“questions”). In order to make each statement complete, the students were asked to cross out any phrases (or items) provided in the questionnaire that they viewed as incorrect (as shown in Appendix D). The questions cover a range of aspects of

biological evolution (A, C, D, G, H and I) and the nature of science related to biological evolution (B, E, F, J, K and L).

More specifically, six questions are related to fundamental concepts of biological evolution. Question A is about the emergence of biological complexity. Questions C, G and I measure understanding of the fundamental concepts of Neo-Darwinian evolution. Question D is about the overall period and process of biological evolution. Question H focuses particularly on the process and period of human evolution.

Another six questions are related to the nature of science related to biological evolution. Question B focuses on acceptance of the theory of evolution among the scientific community and scientists. Questions E and F are about the development of the theory of evolution. Questions J and K are concerned with the nature of scientific knowledge. Question L is related to the justification of the theory of evolution based on the nature of science.

A number of phrases are provided in each question for the students to cross out. They consist of both accurate concepts and the different types of misconceptions. An example of question G and how to respond to it is shown below. In this example, the student crossed out “change in individuals” because he considered that it makes the complete statement incorrect. In other words, he understood that evolution is not about changes in individuals. I use the terminology “question” to refer to the whole statement G, and “item” to refer to the individual part of the statement that can be crossed out.

G. Evolution is about	<div style="border-left: 1px solid black; border-right: 1px solid black; padding: 0 10px;"><div style="text-align: center;"><i>changes in individuals</i> <i>changes in populations</i> <i>a dynamic process</i></div></div>
-----------------------	---

7.4.3 Data analysis

In order to answer the first research question on common and specific misconceptions between the groups of students, item facility analysis is used.

Item facility or Fac (x) is a measure of the difficulty of an item calculated by the mean mark divided by the maximum mark (X_{\max}) of each item according to this following formula.

$$\text{Fac (X)} = \frac{\bar{X}}{X_{\max}}$$

A higher facility indicates an easy item, a lower a difficult item: items having high facility values are those more likely to be answered correctly by students. In the case of the test used here, because each item can either be answered correctly or incorrectly, item facility is equivalent to the proportion of students who answered the item correctly. Therefore, this analysis focuses on items having a lower facility because these are those that the students misunderstand or find particularly difficult, and which teachers have to pay attention to in order to assist their students to overcome difficulties. From a test theory perspective, it is suggested that the desirable facility values should be close to 0.5 while it is undesirable for questions to have the facility values above 0.85 which appear to be too easy or below 0.15 which appear to be too difficult (Mhairi, 2002). However, this study does not aim to develop a test of student understanding but aims to identify potential misconceptions which might be perceived by some students. Therefore, a critical threshold for difficult items of 0.30 and below is selected so as to allow a wider range of concepts which are possibly problematic to be identified. This value is arbitrary, but provides a threshold for items considered to represent difficult items, that I refer to as *common misconceptions*. This chapter presents information on the mean number of misconceptions, as well as details of items with facility values below 0.3.

7.4.4 Scoring system

There were 20 out of 69 items (phrases) that are correct based on the framework used in this analysis. On each item, one point is given to a student who answers correctly (crossed it out if it is wrong or left it if it is right). For example, the student who responded to question G shown above gets three points because he did not cross out the correct items (“changes in population”

and “a dynamic process”) and crossed out the incorrect one (“changes in individuals”). Table 7.4 shows items (appearing in bold) that make each of the statements correct. Appendix I shows the key used to score the participants’ response in which all incorrect items (49 items) representing aspects of misconceptions are crossed out.

	Correct statements in <i>MUSE</i>
A	Complex structures (e.g. human eyes, bacterium flagellum), biological processes (e.g. blood clotting, DNA replication) and various species (e.g. humans, insects) are the results of processes involving natural selection and evolutionary process .
B	Many scientists and members of the scientific community accept and agree that evolution occurs.
C	Darwinian evolution is an explanation of the origin of species from ancestral species and species by means of natural selection .
D	Species existing today have come into being over millions of years or have developed from their early forms over millions of years .
E	The theory of evolution is based on scientific research .
F	The theory of evolution is developed from factual historical data and laboratory data .
G	Evolution is about changes in populations and is a dynamic process .
H	Modern humans are the product of evolutionary processes that have occurred gradually over millions of years .
I	The theory of evolution can be described as different reproductive rates among a population of organisms .
J	Scientific knowledge develops over time and is influenced by scientists’ philosophical assumptions .
K	Science is related to the natural world .
L	None of the phrases make the statement “evolution cannot be scientifically accurate” correct.

Table 7.4: Complete statements in the *Measure for Understanding of Science and Evolution (MUSE)*, correct phrases are in bold.

7.5 Findings

The findings are first presented in the form of descriptive statistics in order to ascertain with what frequency misconceptions appear, and how the number of misconceptions varies between the groups. I then present common misconceptions held by over 30% of respondents. Finally, I consider the overall distribution of misconceptions as a way to rationalise surprising findings in relation to the former two points.

7.5.1 Mean numbers of misconceptions

Table 7.5 shows the mean number and standard deviation of misconceptions across the whole sample, and in the different groups. The data show that, on average, students holding a non-theistic evolutionist position had the smallest number of misconceptions, while those holding a creationist position had the most; divine evolutionists demonstrated an intermediate number of misconceptions.

	Mean number of misconceptions	Standard deviation
Creationists (N=49)	37.90	7.183
Divine Evolutionists (N=48)	35.48	6.140
Non-theistic evolutionists (N=199)	31.48	7.603
Combined (N=296)	33.19	7.727

Table 7.5: Mean numbers of student misconceptions and standard deviations in conjunction with student positions of the origin of life and biodiversity

Figure 7.2 shows the mean number of misconceptions and standard deviation. The figure shows that the same pattern arose for all categories of misconception, with non-theistic evolutionists showing the lowest number of misconceptions per category and creationists the largest.

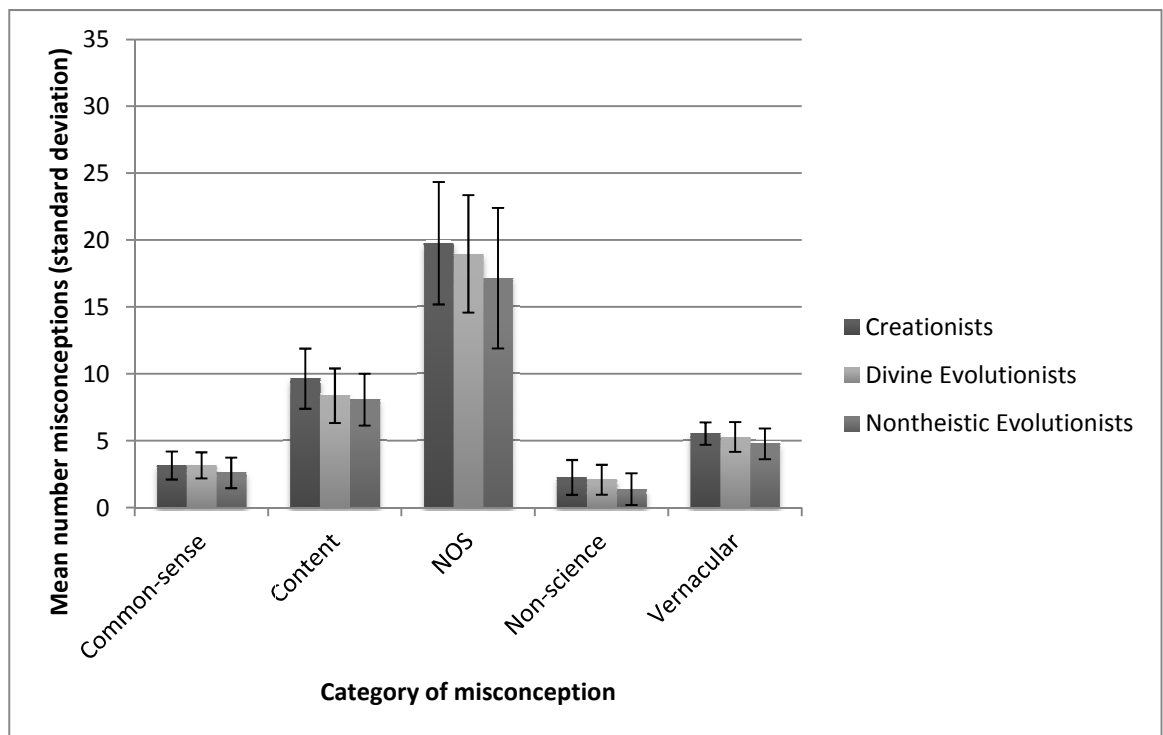


Figure 7.2: The total number of possible misconceptions in each category was: common-sense = 4; content = 21; NOS = 34; Non-science = 4; vernacular = 6)

7.5.2 Common misconceptions about biological evolution

This subsection presents common misconceptions of biological evolution, overall, and as perceived by creationist, divine evolutionist and non-theistic evolutionist students. The findings are based on item facility analysis, and “common misconceptions” are those items whose facility value is less than the threshold value of 0.3. These misconceptions are grouped, as explained earlier, into the following categories: common-sense, content-based, NOS-based and vernacular misconceptions (Table 7.6). Non-scientific misconceptions were not found to be common among any of the three groups of students.

First, creationist, divine evolutionist and non-theistic evolutionist students shared some common-sense misconceptions that evolution is about “changes in individual organisms” and organisms have to “change themselves to meet the needs of their particular environment”. Second, they shared content-based misconceptions primarily associated with Lamarckian explanations: “adaptation of organisms is caused by environmental changes” and the “selection of useful

characteristics of organisms”. Third, another group of misconceptions among the three groups of students is related to aspects of the nature of science. Two main NOS-based misconceptions are associated with the issue of the certainty of scientific knowledge and the justification of the support of the theory of evolution. Specifically, they tended to consider that the theory of evolution “contains weak aspects” and “lacks scientifically valid support”. This could be elaborated by their misjudgement that the theory “provides no convincing evidence” and it “cannot be proven”. Finally, one vernacular misconception was found among the three groups of students: the use of the term “theory”. A large number of them perceived that “evolution is only a theory which is still uncertain”.

Types of misconceptions	Items in <i>MUSE</i>	Creationists	Divine evolutionists	Non-theistic evolutionists
Common sense	changes in individuals	0.12	0.21	0.18
	changes in organisms to meet the needs of their environment	0.22	0.29	0.27
Content-based	adaptation of organisms caused by environmental change	0.16	0.04	0.09
	selection of useful characteristics of organisms	0.27	0.19	0.14
NOS-based	provides no convincing evidence	0.24	0.25	0.24
	cannot be proven	0.20	0.15	0.28
	lacks scientifically valid support	0.20	0.17	0.26
	contains weak aspects	0.22	0.17	0.21
Vernacular	is only a theory which is not certain	0.20	0.15	0.24

Table 7.6: Common misconceptions about evolution among the full group of student participants, with facility values

Specific misconceptions among creationists

Specific misconceptions among creationist students are associated with common-sense, NOS-based and vernacular misconceptions as shown in Table 7.7.

Specifically, both the emergence of the complexity in the biological world and the existence of human beings are predominantly perceived by them as the product of “intelligent design”. One possible explanation is that these common-sense misconceptions can be linked to a non-scientific misconception associated with the religious account of six-day creation (i.e. “species existing today were created within six 24-hour days”). This might lead them to perceive an NOS-based misconception that “evolution contradicts the biblical account of creation”. On this ground, they might reject evolution in any possible ways, such as relying on vernacular misconceptions to claim that the complexity of the biological world and the emergence of human species depend on “chance and randomness”.

Specific misconceptions among non-theistic evolutionists

Specific common misconceptions among non-theistic evolutionist students are related to content-based and NOS-based misconceptions as shown in Table 7.7. Regarding the issue of NOS-based misconceptions, apart from those mentioned above, this group of students was also found to hold the idea that scientific knowledge “involves truth and certainty”. In addition, they tended to perceive that the theory of evolution might not be scientifically accurate because it “is not testable in the laboratory” and “contains ambiguous data”. Regarding content-based misconceptions, one incorrect item found among this group of students is that humans are the product of monkeys’ physical adaptation.

Specific misconceptions among divine evolutionists

Interestingly, a wider range of common misconceptions is found among the divine evolutionist students. Not only did the students share the misconceptions found among both the creationist and the non-theistic evolutionist groups of students (except the adaptation of monkeys), they tended to hold some specific misconceptions as shown in Table 7.7.

	Creationists	Divine evolutionists	Non-theistic evolutionists
Common-sense	<ul style="list-style-type: none"> • Intelligent design in biological world (0.20) • Intelligent design in human evolution (0.29) 	<ul style="list-style-type: none"> • Intelligent design in biological world (0.19) • Intelligent design in human evolution (0.15) 	
Content-based		<ul style="list-style-type: none"> • Evolution explains the origin of life on earth (0.29) • Evolution contradicts the second law of thermodynamics (0.25) 	<ul style="list-style-type: none"> • Evolution is about the adaptation of monkeys (0.30)
NOS-based	<ul style="list-style-type: none"> • Evolution contradicts to the biblical account of creation (0.18) 	<ul style="list-style-type: none"> • Science involves truth and certainty (0.25) • Biological evolution is not testable in the laboratory (0.25) 	<ul style="list-style-type: none"> • Science involves truth and certainty (0.15) • Biological evolution is not testable in the laboratory (0.25)
		<ul style="list-style-type: none"> • Biological evolution is not repeatable in the laboratory (0.17) • Evolutionary theory is based on speculation (0.25) • Evolution depends too much on chance (0.29) 	<ul style="list-style-type: none"> • Evolution is developed from ambiguous data (0.28)
Non-science	<ul style="list-style-type: none"> • Species existing today were created in six 24-hour days (0.29) 	<ul style="list-style-type: none"> • Species existing today have been created over millions of years (0.21) 	
Vernacular	<ul style="list-style-type: none"> • Randomness of the biological word (0.16) • Randomness of human evolution (0.27) • Chance of biological complexity (0.27) 	<ul style="list-style-type: none"> • Randomness of biological world (0.27) • Randomness of human evolution (0.27) • Chance of biological world (0.29) 	

Table 7.7: Specific misconceptions of evolution among the student participants in the different groups, with facility values calculated for the relevant group

Specifically, similar to the creationist students, the divine evolutionist students believed that the emergence of the biological complexity and human beings is the product of “intelligent design” (a common-sense misconception). In addition, they thought that evolution relies on “chance” and “randomness” (vernacular misconceptions). In contrast to the creationist students, these students do not claim that evolution contradicts the religious scripture but that it contradicts

science itself as they perceived that the theory “contradicts the second law of thermodynamics” (a content-based misconception). Moreover, while they perceived that the human beings are the product of intelligent design, the period of “creation” that they understood is much longer (i.e. have been created over millions of years) than the literal interpretation (i.e. six days) and this is also a content-based misconception.

Turning to their misconceptions in relation to the nature of science which can be aligned with those of non-theistic evolutionist students, the divine evolutionist students also considered that science “involves truth and certainty”. In addition, they considered that the theory of evolution relies on “speculation” and it cannot be true as it “depends too much on chance”. In addition, they thought that the theory of evolution is “repeatable” or “testable” in the laboratory. Another content-based misconception among the divine evolutionist students is that they perceived evolution as the explanation of “the origin of life on earth”.

It is possible to conclude based on these findings that the creationist and divine evolutionist students, called theistic students, held common-sense misconceptions about intelligent design and vernacular misconceptions about chance and randomness. In contrast, the divine evolutionist and non-theistic evolutionist students, together called evolutionists, had NOS-based misconceptions about the certainty of scientific knowledge and the testability of evolution.

7.5.3 Full distribution of misconceptions

In this section, I consider the full distribution of misconceptions in the different groups. One motivation for this analysis came from the findings above that although divine evolutionist students held, on average, fewer misconceptions than creationist students, this group demonstrated a larger number of common misconceptions.

Figures 7.3-7.5 shows the full distribution of facility values for the different items, split by group. The figures show that, for 40 items, the facility value was

highest for the nontheistic evolutionists; the divine evolutionists outperformed the other groups in 15 items, and the creationists outperformed the other groups for 13 items²². Importantly, there were several items to which divine evolutionists were more likely to answer incorrectly than creationist students, and where the facility value for divine evolutionists was below the 0.3 threshold while it was above this threshold for creationist students. The data therefore show that there was more spread in the common misconceptions among the divine evolutionists (i.e. spread below the 0.3 facility value threshold). However, this group tended to show less evidence of misconceptions than creationist students when considering the items with higher facility values (“easier” items).

²² There was one item, “species have developed from early forms over millions of years”, to which all students answered correctly.

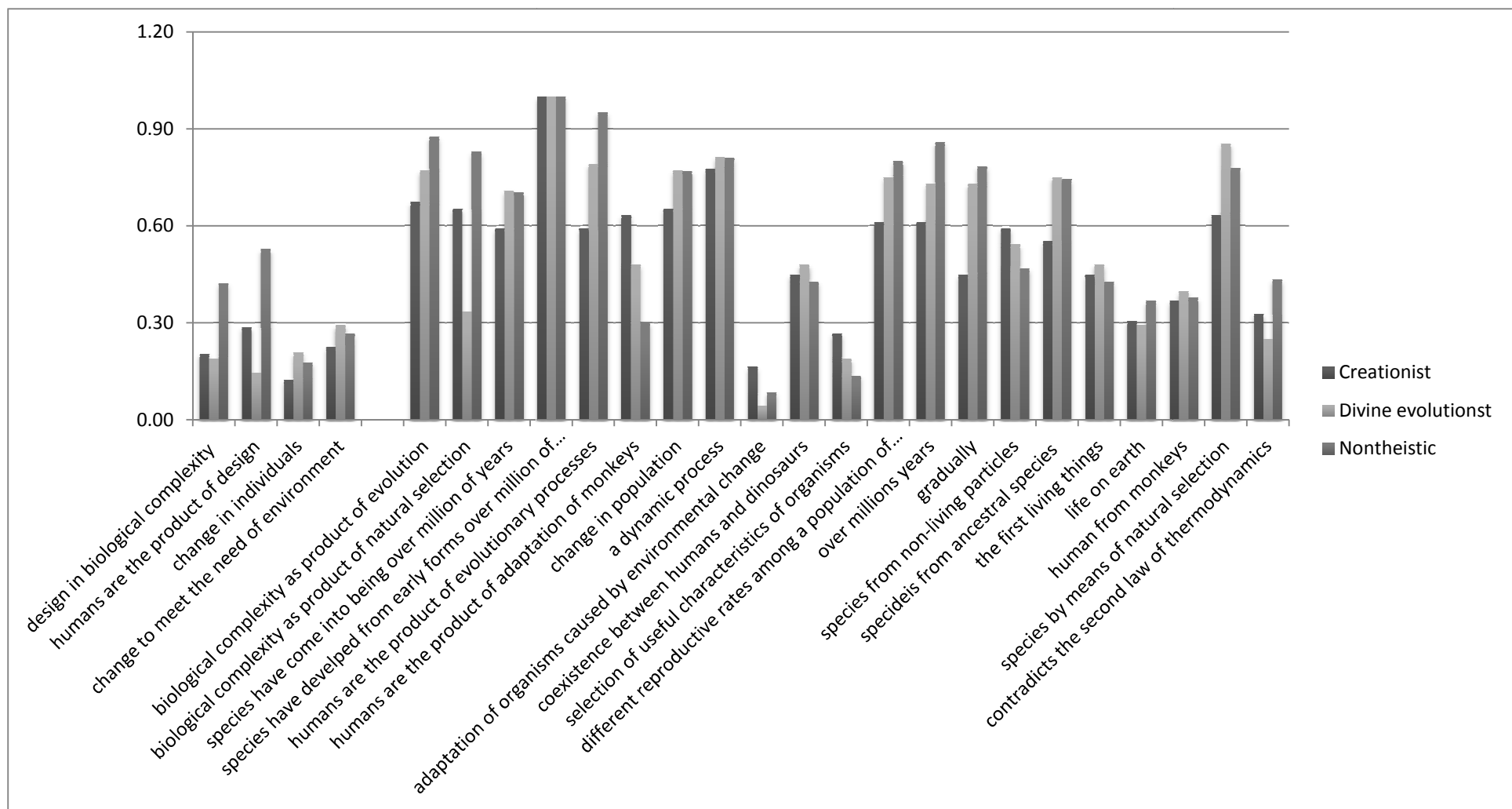


Figure 7.3: the full distribution of facility values for the different items, split by group

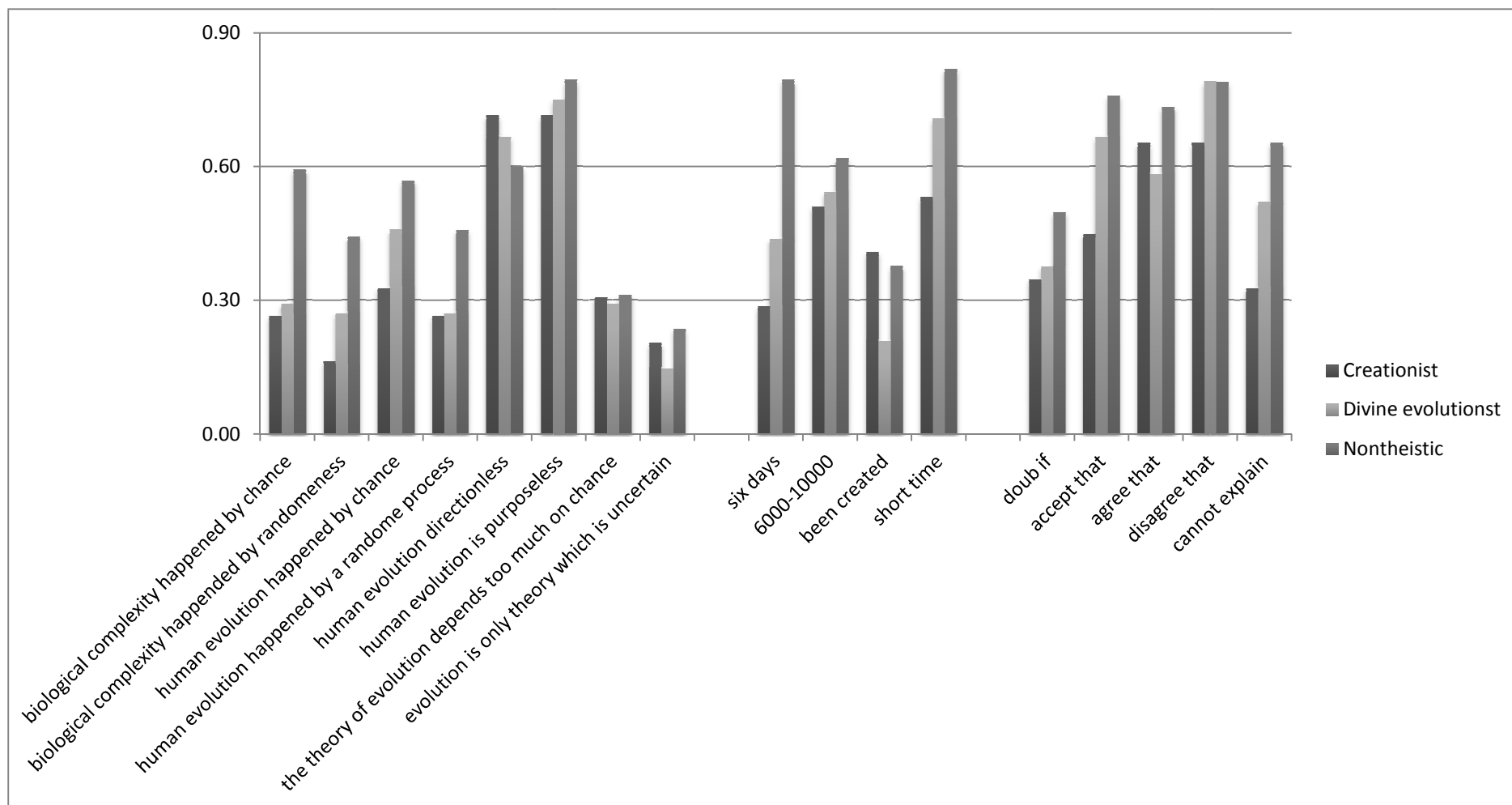


Figure 7.4: the full distribution of facility values for the different items, split by group

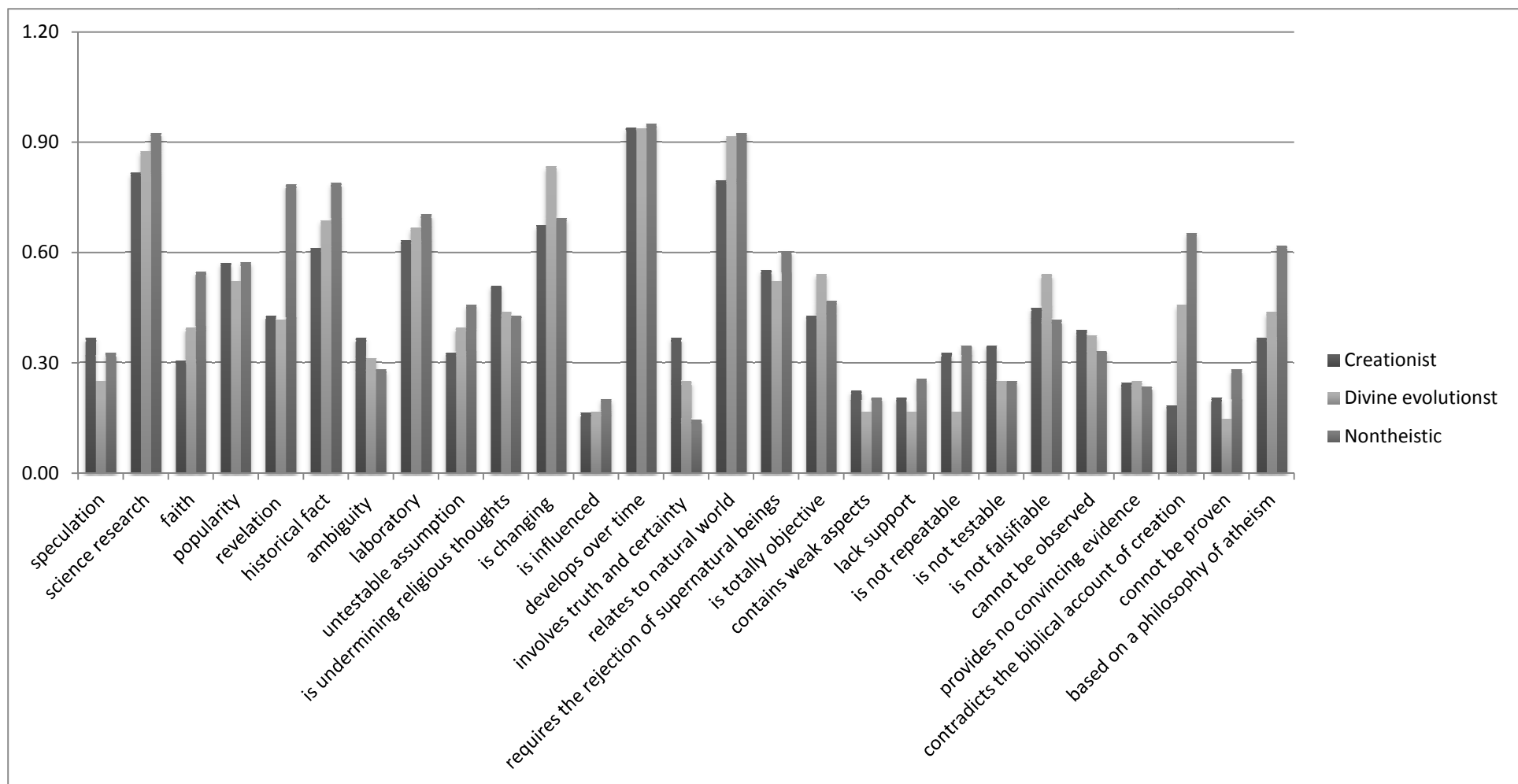


Figure 7.5: the full distribution of facility values for the different items, split by group

7.6 Discussion

The data show that the mean number of misconceptions held by participants was 33, of a total of 69 possible misconceptions tested. The mean number of misconceptions in the non-theistic group was lowest (31) and this number was statistically different at the 5% level from the number of misconceptions among divine evolutionists (35) and creationists (38). I considered as “common” any misconceptions that attracted at least 30% of the relevant group (facility value of 0.3 or lower). The data demonstrated that students in this sample hold a number of shared common misconceptions ranging from common-sense, content-based and NOS-based to vernacular misconceptions. Among the whole sample, 24 misconceptions reached the 30% threshold; among non-theistic evolutionists, this value was 13, while it was 22 among divine evolutionists and 16 among creationists. This initially surprising finding of a larger number of common misconceptions among divine evolutionists was explained by the fact that more misconceptions reached the 30% threshold in this group, even though, on average, each individual held fewer misconceptions.

7.6.1 Shared common misconceptions

First, common sense misconceptions among the three groups of students are related to the idea that evolutionary theory is concerned with changes in organisms and thus organisms have to change or “evolve themselves” in order to meet the needs of their environment. This may be due to the fact that the term “evolve” or “evolution” can be perceived as “active” and “directive” in our common language. Therefore, based on the common use of the term and common sense of naïve learners, evolution can be thought to explain that organisms “need” to develop (themselves) (an active process), in order to survive or become more competitive in the certain environment (a directive process). This active term is not accurate when used in the context of biological evolution. In fact, individual organisms do not “try” to or “have to” evolve, but it is through the mechanism of natural selection that determines which variations existing in the population are able to pass on these traits to the next generations. In addition, as Pongsophon (2006) points out, outcomes of evolution can be either beneficial, neutral or harmful traits depending on

certain environmental conditions. The direction of evolution is actually unpredictable, or at least does not always lead to the improvement of individuals' traits. In sum, biology teachers should be aware of student misconceptions associated with the common sense view that evolution happens in each organism and that organisms can actively evolve to meet the needs of the environment where they live in.

Second, content-based misconceptions among the three groups of student participants are associated with Lamarckian inheritance. This finding is similar to misconceptions found among students in Pongsophon (2006)'s study. They are particularly about the actual explanation of biological evolution. Among the three groups of students in this study, biological evolution is understood to be related to adaptation of organisms caused by environmental change and the selection of useful characteristics of organisms. At a superficial level, this group of misconceptions may be similar to the creationist students. In fact, I think these misconceptions might be developed from the common sense misconceptions. However, I explicitly distinguish them because the common sense misconceptions seem to relate to the active role of individual organisms to evolve by themselves to meet the need of the environment. In contrast, these content-based misconceptions are associated with the active role of the nature that determines which organisms are to survive (in Lamarckian inheritance, it is those that learn how to survive or acquire useful traits). In other words, these misconceptions are related to misunderstanding of natural selection and/or inheritance.

Therefore, this group of misconceptions probably needs to be first dealt with by an explicit explanation that acquired characteristics such as knowledge and hair-length are not passed on to offspring. Then, it needs to be explicit that evolution proceeds by the process of genetic variation and natural selection. An example of the explanation can be that if a population happens to have genetic variation that allows some individuals to survive in a certain environmental condition better than others, or to reproduce their traits more than others, then those individuals will have more offspring in the next generations, and the population will evolve. The source of genetic variation and this level in which

evolution happens should be explicitly explained in the light that Lamarckian explanations are not sufficient to explain how the diversity of life emerged and, in fact, are not consistent with evidence on inheritance.

The third group of shared common misconceptions among the three groups of students is associated with the nature of science as related to biological evolution. They tended to perceive that the theory of evolution cannot be proven, and this might be linked to the view that existing forms of evidence are not convincing, and this perhaps leads to the claim that theory of evolution lacks scientifically valid support and contains “weak aspects”. I assume that this series of misconceptions is generated from two ideas. First, that science must depend on experimental investigations in laboratory settings only. Second, that biological evolution cannot be studied with such basis of investigations. It is therefore useful to point this out to students that many scientific investigations do not involve empirical experiments, such as astronomy and geology. An analogy that might be useful based on this explanation is that like astronomers cannot hold stars and geologists do not have a time machine to return to the past, but their study is based on direct observation. In the same, evolutionary biologists can investigate their ideas about this history of life by making observations in the real world. It is therefore important for teachers to help students evaluate evolutionary evidence from the perspective of scientists (Woods et al., 2011, Colegrav and Collins, 2008). Teaching evolution therefore is not only delivering a package of “complete knowledge” to students, but should also help them see how the knowledge has been developed according to the nature of science.

The final group of common misconceptions among the three groups of students is associated with the use of the term “theory” (a vernacular misconception). Many students in this study considered that “evolution is just a theory”. Scott (2005) clarifies that the term “theory” used in everyday language and by the scientific community is different. In science, a theory must be supported by different forms of evidence, and is not simply a guess as used in the sense of everyday language. It is also helpful for biology teachers to discuss the definition of the term with students more explicitly. Many of those who rejected

evolution adopt this misconception to convince members of the public that evolution is uncertain because it is “just a theory”. Table 7.8 provides a summary of aspects of the main difficulty of each group of misconception that need to be dealt with.

Misconceptions	Aspects that need to be dealt with
Common sense	The active role of individual organisms to “evolve themselves”.
Content-based	The active role of the nature in selecting some phenotypic advantages of organisms, rather than selecting at the genotypic level caused by genetic variation.
NOS-based	The different forms of scientific investigations which do not always involve experiments in a laboratory setting.
Vernacular	The difference between the casual and scientific uses of the term “theory”.

Table 7.8: Main difficulty of each group of misconception

7.6.2 Group-specific misconceptions

The discussion now turns to the specific misconceptions of biological evolution within each of the groups of students. When students holding the three positions on the origin of life and biodiversity are considered in conjunction with their conception about biological evolution, different sets of misconceptions are observed. This discussion starts from specific misconceptions held by the creationist, non-theistic evolutionist and divine evolutionist students, accordingly.

Among the creationist students, apart from the common misconceptions, it is found that they are also challenged by common-sense (i.e. intelligent design), NOS-based (i.e. contradiction between the theory of evolution and the religious text), non-scientific (i.e. six-day period of divine creation), and vernacular misconceptions (i.e. chance and randomness). I believe that these misconceptions that specifically emerged among these students are associated with, or perhaps originated from, religious belief. However, I make my claim explicit here that it is not religious belief per se that brings about these misconceptions. In fact, I argue that it is due to unsophisticated understandings

of the nature of religion. Alexander (2009) asserts that evolutionary theory and belief in divine creation do not contradict one another if the biblical narratives of divine creation are interpreted as they “should be”, that is in the sense of Hebrew poetry used metaphorically for people in that biblical period. Although the teleological argument itself is old,²³ it has been developed by the Intelligent Design community, alongside the use of the terms “chance” and “randomness” in ways that are incompatible with their use in the mainstream scientific community. If a religious believer understands that he or she does not have to choose either evolution or creation, the teleological argument for Intelligent Design and the misuse of the terms “chance” and “random” might seem less convincing. The root of the solution may well be for individuals to better understand the nature of science and the nature of religion. If they understand both science and religion better, there should be no need for this pseudo-knowledge which is neither science nor religion.

In contrast, major challenges among the non-theistic students were associated with NOS-based (i.e. science involves truth and certainty, and evolution is not scientifically accurate because it is not testable and cannot be proven in the laboratory) and content-based misconceptions (i.e. humans are the product of the adaptation of monkeys). Considering their responses to the NOS-based misconceptions, while they thought that science in general involves truth and certainty which may refer to their acceptance of scientific knowledge, the theory of evolution itself is thought to be untested and unproven. This shows that these students have misunderstandings of both the generic aspects of the nature of science and the specific aspects of the nature of evolutionary theory. In addition, it points to conceptual inconsistencies about science. They adopt a very strong position that the knowledge of science in general is true and certain;

²³ Although the teleological argument in the form of Intelligent Design seems to be currently central to creationist concepts and presented as an alternative explanation in opposition to the theory of evolution, the argument has a long origin which is rooted in Greek philosophy. The concept of the designed natural world and its designer appears to have begun with Socrates (470-399), Plato (437-347) and Aristotle (384-322). Later on, Plotinus (205-270) and the Stoics adopted this tradition of teleological reasoning, and developed explanations which were integrated into the Abrahamic religions (Scott, 2005).

however, they become sceptical when considering the theory evolution in particular. First of all, as suggested by Moore (1991) and Smith (2013), science is not the only way of knowing. In fact, scientists propose and test assumptions, being aware that future studies may provide evidence that may lead to refinement, revision, or even rejection of their current understandings. Therefore, science does not lead to “truth” or to “certainty”. In addition, the status of the theory of evolution among the scientific community is not ambiguous but accepted as very important and there is overwhelming consensus regarding it, and a range of different forms of evidence supporting it. Again, in order to minimise these misconceptions, science instruction needs to focus more on how theory of evolution has been developed through series of investigations and forms of evidence.

Adopting both theistic and scientific perspectives, the divine evolutionist students appear to hold the widest range of misconceptions composing all types of misconceptions used in this chapter. Some of their misconceptions are related to the misconceptions held by both the creationists and the non-theistic evolutionists. Like the creationist students, these divine evolutionist students held common-sense misconceptions about intelligent design, and vernacular misconceptions about chance and randomness. Like the non-theistic evolutionist students, the divine evolutionist students perceived NOS-based misconceptions about the certainty of scientific knowledge and the testability of evolution. In addition, they tended to hold other specific misconceptions which are now discussed in turn.

The divine evolutionist students held content-based misconceptions that evolution explains that origin of life on earth and that evolution contradicts the second law of thermodynamic. While the former can be solved by making a clear distinction between abiogenesis and Neo-Darwinian evolution, the latter can be solved by the emphasis that the second law of thermodynamic only applies to closed systems. However, evolution does not take place in a closed system.

In addition, they tend to think that “species existing today have been created over millions of years”. It is understandable why the divine evolutionist students

tended to hold this concept. That is because the statement contains both scientific and religious elements. Therefore, it can be assumed from the statement that the long period of evolution is accepted (i.e. millions of years) which may be scientifically sound, and the role of intelligent design is also accepted as it is clear that species “have been created” and this would make the statement theistically sound for them. I acknowledge that this statement might be interpreted differently and might be scientifically acceptable if the phrase “have been created” is understood as “through evolution”. However, this might not be the case among the divine evolutionist students in this study because they tended to believe that biological evolution is not repeatable in the laboratory, is based on speculation, and depends too much on chance. Indeed, these misconceptions are not aligned with the description of theistic evolution which fully embraces evolution as the process by which the deity brings about biodiversity.

Although theistic evolution is considered by a number of scientists as well as theologians as theologically and scientifically acceptable (Collins 2006; Alexander 2008), it might be too philosophical and complicated to be appropriately held by school students. Therefore, the students need support to clarify their understanding in this position more effectively if it is considered to be a valid position at all. It is unproblematic to urge science teachers to put their actions to help students overcome the challenges related to common-sense, content-based, NOS-based and vernacular misconceptions about biological evolution. However, I wonder whether it is their responsibility to help students maintain appropriate understanding about theistic beliefs. While acknowledging that the divine evolutionist position might be acceptable simply because evolution is accepted, the ultimate cause of things is really beyond the interest of science. To assist students to balance between scientific understanding and theological points of view, I suggest that parents, religious education teachers and church leaders should take their responsibilities alongside science teachers.

Here I come to the contribution of these findings to pedagogical practices. The Committee on Undergraduate Science Education National Research Council (1997b) suggests that one of the effective strategies for helping students

overcome their misconceptions about science is to adopt a “concept maps” approach (p. 30) in which students are encouraged to bring out their perceived concepts and make a group of conceptual interrelationships. They suggest that by adopting this particular instructional approach, students such as the non-theistic evolutionists and divine evolutionists in this study will be able to identify their conceptual inconsistencies and perhaps misconceptions automatically. For example, if the non-theistic evolutionist students accept that the theory of evolution is constructed through scientific research and thus it is theoretically inconsistent for them to perceive that the theory remains untested or unproven. This can be also applied to the creationist students who agree that species existing today have developed from their early forms over millions of years. By holding this scientific understanding, they should be able to question their literal interpretation of the six-day creation when a concept map is drawn.

Many have argued that teaching the nature of science is important for students to learn the theory of evolution. However, I would like to go beyond this concern and claim that it is also important for students to have a sound understanding of the nature of religion as I believe that this can assist students to learn evolution in more appropriate ways. Learning about evolution is a complex phenomenon encompassing different worldviews. Therefore, one-way communication from the scientific angle only might not be sufficient. Religious students need support from their own religious authority to help them reconcile the relationship between the scientific understanding of the explanation of the emergence of life forms and the teaching of the meaning of life and morality.

At a superficial level, it might be expected that divine evolutionist students might not be too difficult for science teachers to work with because they tend to be positive towards evolution as well as science in general. However, these students encounter conceptual inconsistencies such as the gradual process of human evolution, which implies a long period of time, versus the creation account of divine creation in six literal days. Although many scientists attempt to promote the validity of a divine evolution position, it seems to be too philosophical for high school students to understand in the sense that they provide inconsistent answers in relation to this. Indeed, the number of common

misconceptions in this group was higher even than that in the creationist group, although overall the number of misconceptions held by each individual was lower. If promoting reconciliatory positions, teachers therefore need to be aware that doing so may lead to conceptual confusion for some students, and this needs to be addressed.

7.7 Conclusion

This chapter examines student misconceptions about evolution in relation positions of the origin of life and biodiversity using the *Measure for Understanding of Science and Evolution (MUSE)*. Based on item analysis, a range of common misconceptions are found among the student sample associated with common-sense understandings of the active role of organisms to evolve, content-based misconceptions related to Lamarckian theory, NOS-based misconceptions related to the nature of scientific investigation and evaluation of the strength of evolutionary evidence, and vernacular misconceptions related to the term theory. Apart from these shared common misconceptions, the creationist students are found to specifically hold non-scientific and vernacular misconceptions which may be associated with religious belief. The non-theistic evolutionist students are challenged by inconsistencies in ideas related NOS misconceptions. The divine evolutionists also hold some inconsistencies of ideas about evolution which may be caused by the full range of misconceptions identified in this study that they hold. In addition, they hold some misconceptions that are held by both the non-theistic and creationist students.

Chapter 8

Overall Discussion, Implications and Conclusion

8.1 Summary of the main findings

McGrath (2010) points out that the study of the relationship between science and religion has become one of the most fascinating areas of human enquiry which brings together two of the most significant disciplines in contemporary society. A countless number of books and research articles have been published in regards to this area. Moreover, a series of public debates between scientists, philosophers of science and theologians regarding the relationship between science and religion have been organised in different settings such as a public debate, entitled the “God Delusion Debate”, between Richard Dawkins and John Lennox at the University of Oxford in 2007. Within this area of study, a more specific topic, which has become one of the most controversial issues, is the relationship between evolutionary theory and religious accounts of divine creation (Alexander, 2009; Scott, 2005). Among different members of the public, scientists and theologians, this topic is perceived differently, varying from being in conflict to compatible. Indeed, school and university students are no exception, and a large number of research studies have focused attention on these groups.

As a science educator, I am interested in how scientific and religious perspectives impact on student learning of evolutionary biology. The main aim of this thesis, as noted in Chapter 2, was therefore to understand different facets of student learning about evolutionary biology and how these relate to their understandings of both religious and scientific explanations. The facets focused on in this PhD thesis are (1) student *views* of the relationship between science and religion, (2) student *justifications* for levels of acceptance of biological evolution, (3) student *positions* on the relationship between biological evolution and biblical creation in respect to the question on the origin of life

and biodiversity, and (4) student *conceptions* of the theory of evolution and the nature of science in relation to the *positions*. The following paragraphs summarise the key findings of these facets in relation to one another and highlight main contributions of this PhD study to our research community in relation to the patterns of student responses to evolution and their relationship with scientific and religious worldviews. Implications for further research and for practice are already provided in each of the empirical chapters; in the following sections, I therefore focus on the links between the different elements of the thesis in order to draw out educational implications of all of the studies combined for future research and for teaching and learning.

Chapter 4 continued to explore implications of *views* of the relationship between science and religion for learning about evolution initially proposed by Yasri and Mancy (2012) in a larger sample by extending data collection to a large number of students (N=327) in a Christian school in Thailand. This chapter provides the first large-scale findings relating to student views of the relationship between science and religion based on a Christian setting in a Buddhist society. This heterogeneous context contributes to existing knowledge as studies to date have been mainly conducted in Western contexts. It shows that the students hold a range of views of the relationship between science and religion; however, the majority tend to prefer one of the views in which science and religion are considered compatible.

Chapter 5 demonstrates that the student participants held different levels of acceptance of evolution ranging from strong acceptance to strong rejection. It also shows that the majority of those accepting evolution tended not to strongly accept it but hold some reservation, and those rejecting evolution tended not to hold a strong rejection view but made their rejection specifically to some parts of evolution. In addition, the chapter first reports student justifications for the levels of acceptance in the light of the framework of cognitive authority. It shows that those accepting evolution tended to rely on science or refuse religion as a cognitive authority; whereas, those being reserved from strong acceptance, being unsure, and rejecting evolution tended to rely on religion or refuse science as a cognitive authority.

In Chapter 6, scientific and religious worldviews were found to contribute to a diverse range of positions of the origin of life and biodiversity. These appeared to be dependent on the different degrees with which the two worldviews are applied to understandings of the origins, and ranged from literal creationism to atheism. The main finding of this chapter is that a large number of the students tended to adopt a creationist position on the question of the origin of life and biodiversity when they started their high school education. However, their positions were not static but tended to shift towards the more scientifically acceptable positions - in which evolution is accepted - after taking a biology course on evolutionary theory. Interestingly, although students tended to move towards a more scientifically sophisticated positions after taking the course, many found it impossible to leave their religious beliefs and thus they maintained their religious beliefs alongside scientific understanding by choosing either theistic evolution or deistic evolution. Some students who began the course holding an atheistic evolution position also adopted the less strong position of agnostic evolution by the end of the course. In addition, this chapter also highlights two main reasons to which M6 students attributed their change in position after taking the course: changes in understanding of evolutionary theory and changes in the relationship between science and religion. However, they tended to disagree that their change in position was associated with changing in religious beliefs.

Finally, Chapter 7 is the first study large-scale that investigates all currently identified misconceptions about evolution and the nature of science held by students holding different positions on the origin of life and biodiversity. It shows that the non-theistic students demonstrate the lowest number of misconceptions; whereas the creationists demonstrated the largest number. The chapter also presented “common” misconceptions that attracted at least 30% of the relevant group. It demonstrated that students in this sample held a number of shared common misconceptions ranging from common-sense, content-based and NOS-based to vernacular misconceptions, alongside misconceptions specific to each particular group. Among the whole sample, the largest number of common misconceptions is found among divine evolutionists, even though, on

average, each individual in this group held fewer misconceptions compared to the creationist students.

8.2 Links between the four constructs in this study

Based on the main findings from the four empirical chapters, it is hard to deny that learning about evolutionary theory is a complex phenomenon encompassing a range of challenges associated with scientific and religious perspectives. I therefore argue that it is unwise to ignore influences of religious worldviews in evolution education. Biology teachers should therefore be well informed about this in order to be ready to deal with challenges when teaching evolutionary theory. Based on this concern, I now discuss possible links between views of the relationship between science and religion, positions of the origin of life and biodiversity and conceptions of biological evolution and the nature of science in order to explain the phenomenon of learning about evolutionary theory in the real setting encompassing both scientific and religious perspectives, as well as making implications in terms of educational practices.

The primary aim of this thesis has not been to build theory in relation to the different facets explored here, but rather to investigate them separately. However, the following paragraphs represent a modest attempt to suggest some possible relationships between these. This research shows that in evolution education, science and religion are interwoven in at least four aspects: different views of the relationship between science and religion, different sources of cognitive authority related to different levels of acceptance of evolution, different positions of the origin on life and biodiversity, and different sets of conceptual understandings. It is impossible to make any strong claim about which particular aspect acts as a primary cause leading to the others from this current data. In the sections that follow, I nonetheless draw on relevant findings from this thesis and my previous work (Yasri and Mancy, 2012) in order to suggest some links between these four constructs.

In Figure 8.1, I show one possible way in which the constructs investigated in this thesis may interact. This scheme, which should be treated more as a

hypothesis than a claim, relates to the correspondence between compatible combinations of views, forms of cognitive authority and positions. My suspicion is that even if an individual can arrive at these according to a range of mechanisms and starting from different points in the scheme, a change from rejecting to accepting evolution may often require him or her to return to, and reconsider, the most general construct, that of views of the relationship between science and religion. This claim finds some support in the findings of Chapter 6 in which those who changed their position tended to attribute this to changes in their understanding of the evidence for evolution and the relationship between science and religion, but reject the idea that their religious beliefs themselves had changed. It may be that those who did not refer to changes in view, changed position only within the same category in Figure 8.1 (e.g. from theistic to deistic evolution), but this awaits further investigation.

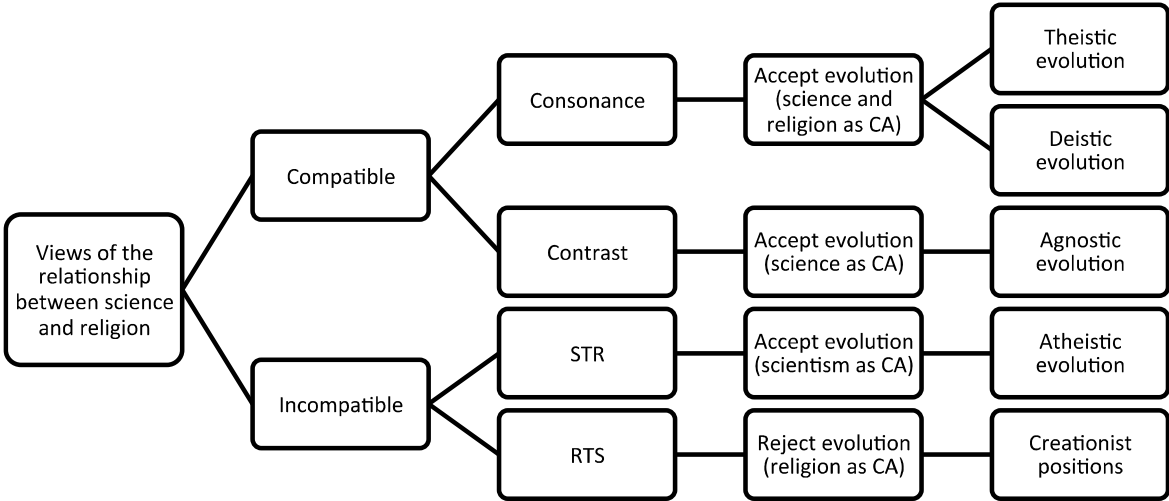


Figure 8.1: Possible links between the constructs in this study

Further evidence can be found in my earlier work (Yasri & Mancy, 2012). When science and religion meet, such as in a biology class on evolutionary theory, the evidence shows that students often make links between the evolutionary content that they learn in the class and their existing beliefs, and this can lead to reconsideration of their views on the possible relationship between the two. However, adopting an initial view of the relationship between science and religion may lead students to depend on different sources of cognitive authority

(second-hand knowledge) for developing or strengthening their own ontology about the relationship between science and religion. As Wilson (1983) notes, it is unlikely that most school students (or even scientists) could gain primary knowledge about evolutionary theory by themselves. Therefore they are likely to rely on a particular source of cognitive authority which appears in different forms such as individuals, texts or institutions (Wiles, 2010). In order to decide which individuals are trustworthy and which books should be read, individual students are likely to be influenced by their view of the relationship between science and religion and their personal associations with individuals who hold particular views. In turn, these sources of cognitive authority solidify how they view the relationship between science and religion.

This is evident in those students holding RTS in Yasri and Mancy (2012)'s study. In their classroom, where evolutionary theory was introduced, they started to perceive that science and religion are incompatible, and that they took the side of religion (RTS). Then they consulted other religious believers (individuals as cognitive authority), books supporting faith and/or books providing arguments against evolution, as well as the Bible (texts as cognitive authority) in order to support and strengthen their RTS views and to conclude that evolution should be rejected. After that, this particular view of the relationship between science and religion, supported by those sources of cognitive authority would underpin how these individual students perceive the relationship between evolutionary theory (as a subset of science) and accounts of divine creation (as a subset of religion), leading to the formation of different positions on the origin of life and biodiversity (and to a creationist position in the case described). These positions then, of course, yield different characteristics of conceptual understanding of biological evolution and the nature of science in which elements related to religious beliefs are prevalent.

In the case of the students taking an RTS view in my earlier work, their decision to seek out sources that were already compatible with their views led to further entrenchment of these. Of course, one can only hypothesise about how these students might have responded to texts that provided them with information from the point of view of compatibility. However, I believe that it is worth

investigating in future work how students choose sources of information and how they might react to sources starting from a compatible viewpoint provided by teachers, especially in the context where religious leaders suggest sources that give incompatible views.

Further evidence that learners link their acceptance of evolution to their viewpoints on science, whether or not they accept or reject evolution, can be found in the work reported in Chapter 5. Indeed, the students from this study who rejected evolution were over seven times more likely to provide justifications that indicated a rejection of science as a cognitive authority than an explanation from religious perspectives. Again, there is no direct evidence in the data that changes in acceptance would require changes in understandings of science, but the data do seem to suggest this possibility.

In relation to the links between views, sources of cognitive authority, and positions or acceptance of evolution, I argue partially from a theoretical perspective, also drawing on my earlier work. From a theoretical perspective, those adopting compatible views are likely to accept evolution based on different sources of cognitive authority. For example, in Yasri and Mancy (2012)'s study, Apai adopting a complementary view and Sadudee adopting a coalescence view relied on both science (i.e. scientific explanations and evidence for evolution to explain) and religion (i.e. God in the Bible as the Ultimate Cause of everything) as cognitive authorities. In contrast, both Mothana and Duangjai appeared to rely on science only as a cognitive authority as they separated other types of knowledge when studying evolutionary theory. However, students viewing science and religion as incompatible are likely to depend on either science or religion as cognitive authority. Generally, those relying on science as a cognitive authority should be expected to accept evolution and are likely to deny religious beliefs on the basis of science; whereas those relying on religion as a cognitive authority or rejecting science as a cognitive authority tend to reject evolution for religious reasons.

Now I will draw the connections between views of the relationship between science and religion with positions of the origin of life and biodiversity. Again,

although these connections are not directly drawn from this PhD study, based on an empirical perspective, findings from the in-depth interviews in Yasri and Mancy (2012) reveal possible connections. In addition, Haught (1995) also points out how views of the relationship between science and religion can be applied to the relationship between biological evolution and biblical creation based on a philosophical perspective.

More specifically, in theory, *RTS* holders should not embrace evolutionary theory based on religious reasons, at least in Christian contexts. They are therefore expected to adopt one of the creationist positions when dealing with the origins. In contrast, not only do *STR* holders accept evolution, are they theoretically expected to expand their understanding of science to disregard religious claims and thus they are assumed to take an atheistic position. Those adopting one of the compatible views are expected to accept evolutionary theory, even though for different reasons as discussed above (Yasri and Mancy, 2012). Students holding a *contrast* view may learn about evolutionary theory in order to fully understand how the nature processes itself without having to concern themselves with religious implications and thus their view can be aligned with agnostic evolution. Unlike these students, holders of a *coalescence* view may accept evolution and learn about it in order to theologically appreciate the work of the divine. They are therefore assumed to take either the position of theistic evolution or deistic evolution. Somewhat similar to the *coalescence* holders, the view taken by *complementary* students may be also aligned with one of these divine evolution positions. However, this group seems to integrate science and religion in a wider sense. More specifically, they may learn evolution in order to understand how the nature was first created and has been sustained by a deity through natural laws and how this completes their biblical understanding of the world.

Theoretically speaking, in sum, those students taking one of the creationist positions would adopt religious accounts of divine creation as their foundation for understanding this aspect of nature. Their understanding should be therefore proximately and ultimately dependent on divine intervention and it is perhaps this that leads to rejection of evolutionary theory. In contrast to this group of

students, those taking non-theistic positions (either agnostic or atheistic) are expected to perceive the biological world and its processes as purely driven by natural forces and wholly governed by the natural laws. However, some might go beyond this realm to reject any religious beliefs on the ground of scientific perspectives. A hybrid between these two worldviews should be found among those taking divine-evolution positions. On the one hand, these students are likely to adopt scientific knowledge to deal with proximate causes of the biological world and its process. On the other hand, they are likely to adopt theistic beliefs when viewing a higher-level ultimate cause. I acknowledge that debates whether divine evolution is scientifically acceptable have not been resolved. However, if the goal of evolution education is to allow students to learn the theory of evolution in order to understand biological processes in which the diversity of life forms emerged and to accept them as scientifically valid explanations (Smith, 2010a), then taking the divine evolution position should be pedagogically unproblematic. In fact, this might be the most comfortable position for school students who hold a particular monotheistic belief to adopt when learning about evolution.

I hope that other researchers interested in evolution education will work to establish or justify these links more thoroughly, particularly the connections between the views of the relationship between science and religion and the positions of the origin of life and biodiversity. Statistically significant associations between these two scales of relationship were not found in this study (data not shown). However, this may be due to the fact that both views of the relationship between science and religion (7 views), and positions of the origin of life and biodiversity (8 positions) were collected as categorical variables which make it difficult to explicitly analyse their statistical links. Although I considered using a Chi-square test to establish their dependence upon one another, a major difficulty is that each of the variables contains more than seven values which make the test invalid because a number of cells in the 8x7 table contain less than 5 counts. I therefore suggest for further studies to design to collect these two variables as numerical (e.g. using 5-point Likert scale items as done with the views of the relationship between science and

religion in this thesis). Alternatively, one could adopt in-depth interviews to validate (or refute) my claim.

8.3 Limitations

Although this study may highlight a number of theoretical contributions, its findings are limited in a range of ways. Specifically, data collection was conducted within the context of the participant school in which only boys study and Christian teachings are blended with the Buddhist community. It is therefore difficult to know to what extent the findings generalise. Different genders may respond differently (Francis and Greer, 1999). In addition, Christian teachings in a Christian school within the Buddhist community might influence student worldviews in different ways compared to a more homogeneous Buddhist society or any religious homogenous contexts. Furthermore, students in different educational levels may arrive at different stages of conceptual development (Evans, 2008) and this may yield different findings. Therefore, further studies are always required to verify both my theoretical assumptions and usefulness of the research instruments.

8.4 Practical implications

I now move to the discussion to some practical implications of this research in educational settings. This thesis contributes to the research community four research tools to examine different aspects of student perceptions of evolution. The first tool can be used to elicit different forms of cognitive authority influencing different levels of acceptance of evolution through the use of the *Acceptance of Biological Evolution Measurement (ABEM)*, based on a five-Likert scale item and a short written task. Second, the *Creation-Evolution Self-Identification Inventory (CESII)* examines positions on the origin of life and biodiversity and changes in the positions based on a selection of a single pre-defined position which closely aligns with one's actual position at a given time. Third, the *Science-Religion Self-Identification Inventory (SRSII)* explores views on the relationship between science and religion based on the selection of one view and five-Likert scale items. Fourth, the *Measure for Understanding of*

Science and Evolution (MUSE) measures student understanding of evolutionary conceptions and the nature of science based on a crossing-out approach.

These tools have been found to be accessible at least among this student sample. *ABEM* is able to elicit the qualitative different levels of acceptance of biological evolution with a separate question assessing justifications for particular levels of acceptance. *CESI* enables researchers to investigate finer variations in positions regarding the origin of life and biodiversity than earlier tools and shows its sensitivity in terms of detecting how positions have been changed through time. In addition, it allows researchers to know what particular reasons contribute to the positional changes. *SRSI* covers a range of views in which science and religion can be related. It has been proven its usefulness, validity and readability not only among this Thai student sample, but also Pakistani and Scottish students as conducted by my colleagues (Yasri, Arthur, Smith & Mancy, 2013). Finally, *MUSE* is useful to explore how individual students or/and groups of students understand and misunderstand evolutionary concepts as well as the nature of science and the biological world. It is also able to trace some specific concepts of evolutionary theory and the nature of science which students may find difficult to understand. Therefore these tools have the potential to contribute to future research. In addition to the research questions raised towards the end of the empirical chapters, their joint use could serve to investigate links between the different aspects.

The tools also have the potential to contribute to pedagogical design and practice directly. It is well documented that many students ranging from school to university levels in different settings have encountered difficulties in accepting the theory of evolution (Berkman et al., 2008, Brem et al., 2003, Clores and Limjap, 2006, Francis et al., 1990, Francis and Greer, 2001, Martin-Hansen, 2008, McKeachie et al., 2002, Özay Köse, 2010, Taber et al., 2011, Yasri and Mancy, 2012). Schilders et al. (2009) argue that it is also difficult for biology teachers as they have to carefully consider students' conflicting ideas alongside preparing how to teach evolution as fundamental concept underlying biological thinking. In order to deal with this issue, Schilders et al. (2009) suggest that teachers ought to investigate how students view the relationship

between evolution and religion. Although I have no objection to this suggestion, I wonder how this could be put into practice in real settings. For example, it might be a great labour and perhaps impossible for a biology teacher to discuss this issue in-depth with every individual student. However, I believe that the instruments used in this PhD research could be used to implement this suggestion, at least to some extent. Instead of having individual discussions, biology teachers may wish to start off discussions about different views of the relationship between science and religion by *SRSII*. Particular ways in which this might be achieved are discussed in more detail in (Yasri, Arthur, Smith & Mancy, 2013). In addition, discussions about different positions of belief about the origin of life and biodiversity can be initiated by *CESII*.

In addition, although most students are aware of the possibility of conflict in the relationship between science and religion as well as evolution and creation, they are perhaps less likely to be informed about possibilities of the compatible; and thus they tend to end up holding the conflict views. This claim corresponds to my personal experience, my experience of working with Christian students in Thailand, and is, to some extent, supported by the changes in position away from conflict positions in the M6 students following their study of evolution and the introduction provided by the teachers. I could see potential of using the suggested research instruments as not only do they allow biology teachers to learn their students' positions, these instruments also allow students to learn a range of views for relating science and religion as well as positions for integrating evolutionary theory to religious accounts of divine creation. This would allow them to be aware of a somewhat fuller range of perceptions which might be a good starting point for further discussions between students and biology teachers or even among peers. This whole process of self-reflection and group discussion might take only a few hours, unless further discussions are required by some individual students. I would recommend that it is helpful to discuss both advantages and disadvantages for understanding of life of each view and position as this would help students develop their own conceptual understanding.

My work to date has convinced me that by being aware of a range of views, many students are likely to prefer one of the compatible views for relating science and religion. In addition, I also believe that when students view science and religion as related in a positive way, their beliefs about the origin of life and biodiversity would be shift towards positions in which evolution is accepted, according to the findings in Chapter 6. However, this needs to be processed together with learning the nature of science, side-by-side. As Schilders et al. (2009) suggest, “many alternative concepts about evolution have their roots in non-standard ideas on the nature of science” (p. 116). I therefore claim that *MUSE* could be used in order to assess how students understand the nature of science. Biology teachers could generate discussions with their students in terms of evolutionary biology and the nature of science by using it. This instrument includes a range of statements both for and against evolution as well as representing both standard and non-standard aspects of the nature of science which is believed to be effective enough to cover a range of conceptions, leading to useful discussions what counts as science and what does not.

Alternatively, teachers interested in using a more qualitative approach to get to know how their students justify their acceptance or rejection of evolution could use *ABEM* instead of or alongside *CESI* and *MUSE*. In fact, *ABEM* could be used as a model for formative assessment in which students are allowed to express their ideas freely from both scientific and religious perspective or any others in order that the teachers would be able improve their teaching methods to help improve student attainment more effectively.

Nonetheless, as argued in Yasri, Arthur, Smith and Mancy (2013), it may be that it is more comfortable to begin teaching on the relationship between science and religion, only moving later to the relationship between evolution and creation. It is hoped that this approach would allow students to become aware of reconciliatory positions prior to explicit discussion of the origins, as an already controversial topic.

8.5 Conclusion

The analysis presented in this thesis demonstrates that in the Christian school in Thailand where this study took place, student responses to evolution tend to be positive as many hold compatible views of the relationship between science and religion, intermediate levels of acceptance of evolution and reconciliatory positions of the relationship between biological evolution and biblical creation in respect to the question on the origin of life and biodiversity. Although some students may hold negative responses to evolution at a given time, this study provides some support to the idea that these learners can develop their scientific sophistication and acceptance of evolution. The data show that this can occur without them having to fundamentally change their religious beliefs through a better understanding of the nature of science particularly the evidence for evolution, and a positive way of viewing the relationship between science and religion. I therefore agree with many science educators that it is important to focus on the teaching of the nature of science in order for students to understand what science is, how it works and how it is different from non-science as well as pseudoscience.

References

- Abd-El-Khalick, F. 2012. Examining the Sources for our Understandings about Science: Enduring confluences and critical issues in research on nature of science in science education. *International Journal of Science Education*, 34, 353-374.
- Alexander, D. 2009. *Creation or evolution: Do we have to choose?*, Oxford, Monarch Books.
- Alexander, D. R. 2007. Models for relating science and religion. *Faraday Paper* [Online]. Available: <http://www.st-edmunds.cam.ac.uk/faraday/papers.php>.
- Allgaier, J. & Holliman, R. 2006. The emergence of the controversy around the theory of evolution and creationism in UK newspaper reports. *The Curriculum Journal*, 17, 263-279.
- Alter, B. J. & Nelson, C. E. 2002. Perspective: teaching evolution in higher education. *Evolution*, 56, 1891-1901.
- Alters, B. J. & Nelson, C. E. 2002. Perspective: Teaching Evolution in Higher Education. *Evolution*, 56, 1891-1901.
- Anderson, R. D. 2007. Teaching the theory of evolution in social, intellectual, and pedagogical context. *Science Education*, 91, 664-677.
- Asghar, A., Wiles, J. R. & Alters, B. 2010. The origin and evolution of life in Pakistani High School Biology. *Journal of Biological Education*, 44, 65-71.
- Barbour, I. G. 1990. *Religion in an Age of Science*, London, SCM Press.
- Berkman, M. B., Pacheco, J. S. & Plutzer, E. 2008. Evolution and Creationism in America's Classrooms: A National Portrait. *PLoS Biol*, 6, 920-924.
- Berry, R. 2007. Creation and evolution: Not creation or evolution. *Faraday paper* [Online], 12. Available: <http://www.st-edmunds.cam.ac.uk/faraday/papers.php>.
- Billingsley, B., Taber, K., Riga, F. & Newdick, H. 2012. Secondary School Students' Epistemic Insight into the Relationships Between Science and Religion—A Preliminary Enquiry. *Research in Science Education*, 1-18.
- Biological Sciences Curriculum Study 2005. *The nature of science and the study of biological evolution*, Washington DC, NSTA Press.

- Brem, S. K., Ranney, M. & Schindel, J. 2003. Perceived consequences of evolution: College students perceive negative personal and social impact in evolutionary theory. *Science Education*, 87, 181-206.
- Charlesworth, B. & Charlesworth, D. 2003. *Evolution: A Very Short Introduction*, Oxford, Oxford University Press.
- Cho, M.-H., Lankford, D. & Wescott, D. 2011. Exploring the Relationships among Epistemological Beliefs, Nature of Science, and Conceptual Change in the Learning of Evolutionary Theory. *Evolution: Education and Outreach*, 4, 313-322.
- Cioccolanti, S. 2007. *From Buddha to Jesus: An Insider's View of Buddhism & Christianity*, Oxford, Monarch Books.
- Clores, M. & Limjap, A. 2006. Diversity of students' beliefs about biological evolution. *Asia Pacific Journal of Education*, 26, 65-77.
- Cobern, W. 2000. The Nature of Science and the Role of Knowledge and Belief. *Science & Education*, 9, 219-246.
- Cobern, W. W. 1989. Worldview theory and science education research: Fundamental epistemological structure as a critical factor in science learning and attitude development. *Scientific Literacy and Cultural Studies Project*.
- Cobern, W. W. 1997. Public understanding of science as seen by the scientific community: Do we need to re-conceptualize the challenge and to re-examine our own assumptions? In: S. SJØBERG, E. K. (ed.) *Science, Technology and Citizenship: The Public Understanding of Science and Technology in Science Education and Research Policy*. Oslo, Norway: Norwegian Institute for Studies in Research and Higher Education.
- Colegrav, N. & Collins, S. 2008. Experimental evolution: experimental evolution and evolvability. *Heredity*, 100, 464-470.
- Collins, F. 2006. *The Language of God: A Scientist Presents Evidence for Belief*, New York, Free Press.
- Committee on Undergraduate Science Education National Research Council 1997a. *Science Teaching Reconsidered: A Handbook*, Washington DC, The National Academies Press.

- Committee on Undergraduate Science Education National Research Council
1997b. *Science Teaching Reconsidered: A Handbook*, Washington, D.C.,
The National Academies Press.
- Crabtree, B. F. & Miller, W. L. 1992. *Doing qualitative research*, London, Sage.
- Dagher, Z. R. & Boujaoude, S. 1997. Scientific views and religious beliefs of
college students: The case of biological evolution. *Journal of Research in
Science Teaching*, 34, 429-445.
- Dagher, Z. R. & Boujaoude, S. 2005. Students' perceptions of the nature of
evolutionary theory. *Science Education*, 89, 378-391.
- Darwin, C. 1859. *On the Origin of Species*, London, John Murray.
- Deniz, H., Donnelly, L. & Yilmaz, I. 2008. Exploring the factors related to
acceptance of evolutionary theory among Turkish preservice biology
teachers: Toward a more informative conceptual ecology for biological
evolution. *Journal of Research in Science Teaching*, 45, 420-443.
- Dobzhansky, T. 1973. Nothing in biology makes sense except in the light of
evolution. *The American Biology Teacher*, 35, 125-129.
- Donnelly, L., Kazempour, M. & Amirshokoochi, A. 2009. High school students'
perceptions of evolution instruction: Acceptance and evolution learning
experiences. *Research in Science Education*, 39, 643-660.
- Downie, J. & Barron, N. 2000. Evolution and religion: attitudes of Scottish first
year biology and medical students to the teaching of evolutionary biology.
Journal of Biological Education, 34, 139-146.
- Driver, R., Leach, J., Millar, R. & Scott, P. 1996. *Young people's images of
science*, Buckingham, Open University Press.
- Eggen, P. & Kauchak, D. 2004. *Educational Psychology: Windows, Classrooms*,
Upper Saddle River, Pearson Prentice Hall.
- Evans, E. M. 2008. Conceptual change and evolutionary biology: A
developmental analysis. In: VOSNIADOU, S. (ed.) *International handbook
of research on conceptual change*. New York: Routledge.
- Eve, R., Losh, S. & Nzekwe, B. 2010. Lessons from the Social Psychology of
Evolution Warfare: Good Science Alone is not Enough. *Evolution:
Education and Outreach*, 3, 183-192.

- Foster, C. 2012. Creationism as a Misconception: Socio-cognitive conflict in the teaching of evolution. *International Journal of Science Education*, 34, 2171-2180.
- Francis, L., Gibson, H. & Fulljames, P. 1990. Attitude towards Christianity, Creationism, Scientism and Interest in Science Among 11-15 Year Olds. *British Journal of Religious Education*, 13, 4-17.
- Francis, L. & Greer, J. 1999. Attitudes towards creationism and evolutionary theory: the debate among secondary pupils attending Catholic and Protestant schools in Northern Ireland. *Public Understanding of Science*, 8, 93-103.
- Francis, L. & Greer, J. 2001. Shaping Adolescents' Attitudes towards Science and Religion in Northern Ireland: the role of scientism, creationism and denominational schools. *Research in Science & Technological Education*, 19, 39-53.
- Fulljames, P., Gibson, H. & Francis, L. 1991. Creationism, Scientism, Christianity and Science: A Study in Adolescent Attitudes. *British Educational Research Journal*, 17, 171-190.
- Gauch, H., Jr. 2009. Science, Worldviews, and Education. In: MATTHEWS, M. (ed.) *Science, Worldviews and Education*. Netherlands: Springer.
- González Galli, L. & Meinardi, E. 2011. The Role of Teleological Thinking in Learning the Darwinian Model of Evolution. *Evolution: Education and Outreach*, 4, 145-152.
- Gould, J. 2002. *Rock of Ages: Science and religion in the fullness of life*, New York, Ballantín Books.
- Gregory, T. 2009. Understanding Natural Selection: Essential Concepts and Common Misconceptions. *Evolution: Education and Outreach*, 2, 156-175.
- Haught, J. F. 1995. *Science and Religion: from Conflict to Conversation*, New York, Paulist Press.
- Hokayem, H. & Boujaoude, S. 2008. College students' perceptions of the theory of evolution. *Journal of Research in Science Teaching*, 45, 395-419.
- Ingram, E. L. & Nelson, C. E. 2006. Relationship between achievement and students' acceptance of evolution or creation in an upper-level evolution course. *Journal of Research in Science Teaching*, 43, 7-24.

- Krell, K. 2005. The Crown and Climax of Creation (Genesis 1:26-2:3). *The Book of Beginnings: Genesis* [Online]. Available: <http://bible.org/seriespage/crown-and-climax-creation-genesis-126-23>.
- Kulas, J. T., Stachowski, A. A. & Haynes, B. A. 2008. Middle response functioning in Likert-responses to personality items. *Journal of Business and Psychology*, 22, 251-259.
- Ladine, T. 2009. Attitudes of Students at a Private Christian Liberal Arts University Toward the Teaching of Evolution. *Evolution: Education and Outreach*, 2, 386-392.
- Larson, E. J. & Witham, L. 1998. Leading scientists still reject God. *Nature*, 394, 313-313.
- Leakey, R. 1996. *The Origin Of Humankind*, New York, BasicBooks.
- Lederman, N. G. 1995. Suchting on the nature of scientific thought: Are we anchoring curricula in quicksand? *Science & Education*, 4, 371-377.
- Lederman, N. G., Abd-El-Khalick, F., Bell, R. L. & Schwartz, R. S. 2002. Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39, 497-521.
- Lennox, J. C. 2007. *God's Undertaker: Has Science Buried God?*, Oxford, Lion Hudson plc.
- Lombrozo, T., Thanukos, A. & Weisberg, M. 2008. The Importance of Understanding the Nature of Science for Accepting Evolution. *Evolution: Education and Outreach*, 1, 290-298.
- Mahner, M. & Bunge, M. 1996. Is religious education compatible with science education? . *Science and Education*, 5, 101-123.
- Martin-Hansen, L. 2008. First-Year College Students' Conflict with Religion and Science. *Science & Education*, 17, 317-357.
- Martin, J. W. 2010. Compatibility of major US Christian denominations with evolution. *Evolution: Education and Outreach*, 3, 420-431.
- Martin, R., Sexton, C. & Gerlovich, J. 2002. *Teaching Science for all Children: Methods for Constructing Understanding*, Boston, Allyn and Bacon.
- Matthews, M. R. 2009. Science, worldviews and education: an introduction. *Science & Education*, 18, 641-666.

- Mazur, A. 2004. Believers and disbelievers in evolution. *Politics and the Life Sciences*, 23, 55-61.
- Mccollom, T. M. 2013. Miller-Urey and Beyond: What Have We Learned About Prebiotic Organic Synthesis Reactions in the Past 60 Years? *Annual Review of Earth and Planetary Sciences*, 41.
- Mcgrath, A. E. 2010. *Science and Religion: A New Introduction*, Singapore, Willey-Blackwell.
- Mckeachie, W., Lin, Y. & Strayer, J. 2002. Creation vs. evolution beliefs: effects on learning biology. *The American Biology Teacher*, 64, 189-192.
- Mead, L. & Scott, E. 2010. Problem Concepts in Evolution Part I: Purpose and Design. *Evolution: Education and Outreach*, 3, 78-81.
- Meadows, L., Doster, E. & Jackson, D. 2000. Managing the conflict between evolution & religion. *The American Biology Teacher*, 62, 102-107.
- Mhairi, M. 2002. A Summary of Methods of Item Analysis. Available: <http://caacentre.lboro.ac.uk/dldocs/BP2final.pdf>.
- Midgley, M. 1985. *Evolution as a Religion: Strange Hopes and Stranger Fears*. London: Routledge.
- Miller, J. D., Scott, E. C. & Okamoto, S. 2006. Public acceptance of evolution. *SCIENCE-NEW YORK THEN WASHINGTON-*, 313, 765.
- Moore, J. A. 1984. Science as a way of knowing—Evolutionary biology. *American Zoologist*, 24, 467-534.
- Moore, J. A. 1991. Science as a Way of Knowing—VII A Conceptual Framework for Biology Part III. *American Zoologist*, 31, 349-470.
- Nadelson, L. 2009. Preservice Teacher Understanding and Vision of how to Teach Biological Evolution. *Evolution: Education and Outreach*, 2, 490-504.
- Nehm, R. H. & Schonfeld, I. 2007. Does increasing biology teacher knowledge about evolution and the nature of science lead to greater advocacy for teaching evolution in schools? *Journal of Science Teacher Education*, 18, 699-723.
- Nelson, C. E. 1986. Creation, Evolution, or Both? A Multiple Model Approach. In: HANSON, R. (ed.) *Science and Creation*. New York: Macmillan.
- Nord, W. A. 1999. Science, religion, and education. *Phi Delta Kappan*, 81, 28-33.

- Özay Köse, E. 2010. Biology students' and teachers' religious beliefs and attitudes towards theory of evolution. *Hacettepe Universitesi Journal of Education*, 38, 189-200.
- Palmer, B. 2013. A review on the spontaneous formation of the building blocks of life and the generation of a set of hypotheses governing universal abiogenesis. *International Journal of Astrobiology*, 12, 39-44.
- Perry, W. G., Jr. 1970. *Forms of Intellectual and Ethical Development in the College Years: A Scheme*, New York, Holt, Rinehart, and Winston.
- Peters, T. 2007. Models of God. *Philosophia*, 35, 273-288.
- Pickrell, J. 2006. Top 10: Dinosaur Myths. *NewScientist*.
- Polkinghorne, J. C. 1986. *One World: The Interaction of Science and Theology*, London, SPCK.
- Pongsophon, P. 2006. *Enhancing Thai students' scientific understanding of evolution: A social constructivist approach*. PhD Thesis, Kasetsart University.
- Pope John Paul II. 1996. Message to the pontifical academy of sciences: on evolution. Available: <http://www.ewtn.com/library/papaldoc/jp961022.htm>.
- Pope Pius XII. 1950. *Humani Generis* (Concerning Some False Opinions Threatening to Undermine the Foundations of Catholic Doctrine). Available: <http://www.ewtn.com/library/ENCYC/P12HUMAN.HTM>.
- Preston, J. & Epley, N. 2009. Science and God: an automatic opposition between ultimate explanations. *Journal of experimental Social Psychology*, 45, 238-241.
- Reich, K. H. 2010. *Developing the Horizons of the Mind: Relational and Contextual Reasoning and the Resolution of Cognitive Conflict*, Cambridge, Cambridge University Press.
- Reiss, M. J. 2008. Should science educators deal with the science/religion issue? *Studies in Science Education*, 44, 157-186.
- Reiss, M. J. 2009a. The relationship between evolutionary biology and religion. *Evolution*, 63, 1934-1941.
- Reiss, M. J. 2009b. Science and religion: implications for science educators. *Cultural Studies of Science Education*, 5, 91-101.

- Rice, J. W., Warner, D. A., Kelly, C. D., Clough, M. P. & Colbert, J. T. 2010. The theory of evolution is not an explanation for the origin of life. *Evolution: Education and Outreach*, 3, 141-142.
- Rieh, S. Y. & Hilligoss, B. 2008. College students' credibility judgments in the information-seeking process. In: METZGER, M. J. & FLANAGIN, A. J. (eds.) *Digital media, youth, and credibility-the John D. and Catherine T. MacArthur Foundation series on digital media and learning*. Cambridge, MA: The MIT Press.
- Roth, W.-M. 1997. The interaction of students' scientific and religious discourses: Two case studies. *International Journal of Science Education*, 19, 125-146.
- Rutledge, M. & Sadler, K. 2007. Reliability of the Measure of Acceptance of the Theory of Evolution (MATE) instrument with university students. *American Biology Teacher*, 69, 332-335.
- Rutledge, M. & Warden, M. 2000. Evolutionary theory, the nature of science & high school biology teachers: Critical relationships. *The American Biology Teacher*, 62, 23-31.
- Samarapungavan, A. & Wiers, R. W. 1997. Children's thoughts on the origin of species: A study of explanatory coherence. *Cognitive Science*, 21, 147-177.
- Schilders, M. S., Peter, P. E. & Boersma, K. 2009. Worldviews and evolution in the biology classroom. *Journal of Biological Education (Society of Biology)*, 43, 115-120.
- Scott, E. C. 2004. *Evolution vs Creationism: An Introduction*, California, University of California Press.
- Scott, E. C. 2005. *Evolution vs Creationism: An Introduction*, California, University of California Press.
- Sheldon, R. B. Historical Development of the Distinction between Bio-and Abiogenesis. Proc. of SPIE Vol, 2005. 59061I-1.
- Shipman, H. L., Brickhouse, N. W., Dagher, Z. & Letts, W. J. 2002. Changes in student views of religion and science in a college astronomy course. *Science Education*, 86, 526-547.
- Sinatra, G., Brem, S. & Evans, E. 2008. Changing minds? Implications of conceptual change for teaching and learning about biological evolution. *Evolution: Education & Outreach*, 1, 189-195.

- Sinclair, A., Pendarvis, M. P. & Baldwin, B. 1997. The relationship between college zoology students' beliefs about evolutionary theory and religion. *Journal of. Research and Development in Education*, 30, 118-125.
- Smith, M. 2010a. Current Status of Research in Teaching and Learning Evolution: I. Philosophical/Epistemological Issues. *Science & Education*, 19, 523-538.
- Smith, M. 2010b. Current Status of Research in Teaching and Learning Evolution: II. Pedagogical Issues. *Science & Education*, 19, 539-571.
- Smith, M. 2013. The Role of Authority in Science and Religion with Implications for Science Teaching and Learning. *Science & Education*, 22, 605-634.
- Smith, M. & Scharmann, L. 1999. Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. *Science Education*, 83, 493-509.
- Southcott, R. & Downie, J. R. 2012. Evolution and Religion: Attitudes of Scottish Bioscience Students to the Teaching of Evolutionary Biology. *Evolution: Education and Outreach*, 5, 301-311.
- Stearns, S. C. & Hoekstra, R. F. 2005. *Evolution*, Oxford, Oxford University Press.
- Stolberg, T. L. 2007. The Religio-scientific Frameworks of Pre-service Primary Teachers: An analysis of their influence on their teaching of science. *International Journal of Science Education*, 29, 909-930.
- Taber, K. S., Billingsley, B., Riga, F. & Newdick, H. 2011. Secondary students' responses to perceptions of the relationship between science and religion: Stances identified from an interview study. *Science Education*, 95, 1000-1025.
- The Pew Forum on Religion and Public Life 2008. Religious Beliefs and Practices: Diverse and Politically Relevant June 2008. Pew Research Center.
- Thompson, F. & Logue, S. 2006. An exploration of common student misconceptions in science. *International Education Journal*, 7, 553-559.
- Tracy, T. 2008. Evolutionary Theologies and Divine Action. *Theology and Science*, 6, 107-116.
- Verhey, S. D. 2005. The Effect of Engaging Prior Learning on Student Attitudes toward Creationism and Evolution. *BioScience*, 55, 996-1003.
- Wiles, J. 2010. Overwhelming scientific confidence in evolution and its centrality in science education and the public disconnect. *Science Education Review*, 9, 18-27.

- Williams, J. D. 2009. Belief versus acceptance: why do people not believe in evolution? *Bioessays*, 31, 1255-1262.
- Wilson P. 1983. *Second-hand knowledge: An inquiry into cognitive authority*. London: Greenwood Press.
- Winslow, M. W., Staver, J. R. & Scharmann, L. C. 2011. Evolution and personal religious belief: Christian university biology-related majors' search for reconciliation. *Journal of Research in Science Teaching*, 48, 1026-1049.
- Woods, C. S. & Scharmann, L. C. 2001. High school students' perceptions of evolutionary theory. *Electronic Journal of Science Education*, 6.
- Woods, R. J., Barric, J. E., Cooper, T. F., Shrestha, U., Kauth, M. R. & Lenski, R. E. 2011. Second-order selection for evolvability in a large *Escherichia coli* population. *Science (New York, N.Y.)*, 331, 1433-6.
- Yasri, P., Arthur, S., Smith, M. U. & Mancy, R. 2013. Relating Science and Religion: An Ontology of Taxonomies and Development of a Research Tool for Identifying Individual Views. *Science & Education*, 22, 2679-2707.
- Yasri, P. & Mancy, R. 2012. Understanding student approaches to learning evolution in the context of their perceptions of the relationship between science and religion *International Journal of Science Education*.

Appendix A: The Science-Religion Self-Identification Inventory (SRSII)

How do you view the relationship between science and religion?

	Views	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
A	Some aspects of science appear to conflict with religion but I do not really understand the conflicts.					
B	Some aspects of science appear to conflict with religion. When there are different answers to the same questions, I think only science provides true answers.					
C	Some aspects of science appear to conflict with religion. When there are different answers to the same questions, I think only religion provides true answers.					
D	Science and religion do not conflict because their role is to answer different questions (e.g. science deals with questions about the physical universe, while religion addresses questions of ethics, value and purpose).					
E	Science and religion do not conflict because they construct knowledge in different ways (e.g. scientific knowledge is constructed through testing explanations, while religious knowledge is constructed by interpreting religious texts).					
F	It must be possible to combine science and religion together because they provide the same answers to the same questions.					
G	Science and religion are complementary. Both are useful to understand all aspects of life.					
H	Other :					

Please choose one that best describes your personal view

(write a letter here)

Appendix B: Acceptance of Biological Evolution Measurement (ABEM)

What do you think of this statement?

Statement	Strongly accept	Accept with reservations	Not sure	Reject some parts	Strongly reject
The modern theory of evolution through variation, inheritance and natural selection is the best current scientifically valid explanation of the past and current biodiversity on the planet Earth.					

Please explain why you have selected this answer?

Appendix C: The Creation-Evolution Self-Identification Inventory (CESII)

Which of the following best fits your view? (M4 and M5 students only)

	Views	Your view (tick one)
A	All forms of life were first brought into being by a deity in more or less their present form at the same time.	
B	Some forms of life evolved from earlier forms created by a deity, but human beings were created in more or less their present form.	
C	Some forms of life evolved from earlier forms created by a deity, but higher taxonomical species such as reptiles, birds and mammals were created in more or less their present form.	
D	All forms of life were gradually created over time by a deity in more or less their present form.	
E	All forms of life evolved from earlier forms, but a deity intervenes from time to time to shape or override the evolutionary processes.	
F	All forms of life evolved from earlier forms, but life and evolution were first set in motion by a deity and then left running without any additional intervention.	
G	Life emerged from non-living particles and then all current forms evolved from these earlier forms. A deity may exist, however, this is out of scope of evolutionary theory.	
H	Life emerged from non-living particles and then all current forms evolved from these earlier forms. No deity has ever played any role in the evolution of life on Earth.	
I	I do not know.	
J	Other :	

Which of the following best fit your view at the start of your studies and now? (For M6s)

	Views	Tick one	
		View at start	View now
A	All forms of life were first brought into being by a deity in more or less their present form at the same time.		
B	Some forms of life evolved from earlier forms created by a deity, but higher taxonomical species such as reptiles, birds and mammals were created in more or less their present form.		
C	Some forms of life evolved from earlier forms created by a deity, but human beings were created in more or less their present form.		
D	All forms of life were gradually created over time by a deity in more or less their present form.		
E	All forms of life evolved from earlier forms, but a deity intervenes from time to time to shape or override the evolutionary processes.		
F	All forms of life evolved from earlier forms, but life and evolution were first set in motion by a deity and then left running without any additional intervention.		
G	Life emerged from non-living particles and then all current forms evolved from these earlier forms. A deity may exist, however, this is out of scope of evolutionary theory.		
H	Life emerged from non-living particles and then all current forms evolved from these earlier forms. No deity has ever played any role in the evolution of life on Earth.		
I	I do not know.		
J	Other :		

If you have changed your view, which of the following aspects have led to the change?

Statements	Strongly agree	Agree	Don't know	Disagree	Strongly disagree
There has been a change in my understanding of the strength of the evidence					
There has been a change in my religious beliefs					
There has been a change in my understanding of the way evolution relates to my religious beliefs					
Other.....					

Appendix D: The Measure for Understanding of Science and Evolution (MUSE)

Please cross out all phrases in the boxes provided that make the sentences A-L incorrect. Note that you may need to cross out no phrases, one phrase or all the phrases.

A. Complex structures (e.g. human eyes, bacterium flagellum), biological processes (e.g. blood clotting, DNA replication) and various species (e.g. humans, insects) are the results of processes involving

- *natural selection*
- *intelligent design*
- *evolutionary processes*
- *chance*
- *randomness*

B. Many scientists and members of the scientific community

- *doubt if*
- *accept that*
- *agree that*
- *disagree that*
- *cannot explain*

evolution occurs.

C. Darwinian evolution is an explanation of the origin of

- *species from non-living particles*
- *species from ancestral species*
- *the first living things*
- *life on earth*
- *humans from monkeys*
- *species by means of natural selection*

D. Organisms existing today	<ul style="list-style-type: none"> • <i>have come into being over millions of years</i> • <i>were created in six days</i> • <i>were created between 6000-10000 years ago</i> • <i>have been created over millions of years</i> • <i>have developed from their early forms over millions</i>
-----------------------------	--

E. The theory of evolution is based on	<ul style="list-style-type: none"> • <i>speculation</i> • <i>scientific research</i> • <i>faith</i> • <i>popularity</i> • <i>revelation</i>
--	--

F. The theory of evolution is developed from	<ul style="list-style-type: none"> • <i>factual historical data</i> • <i>ambiguous data</i> • <i>laboratory data</i> • <i>untestable assumptions</i>
--	--

G. Evolution is about	<ul style="list-style-type: none"> • <i>changes in individuals</i> • <i>changes in populations</i> • <i>a dynamic process</i>
-----------------------	--

H. Modern humans are the product of	<ul style="list-style-type: none"> • <i>evolutionary processes</i> • <i>design</i> • <i>chance processes</i> • <i>random processes</i> • <i>directionless processes</i> • <i>purposeless process</i> • <i>adaptation of monkeys</i> 	that have occurred	<ul style="list-style-type: none"> • <i>over millions of years</i> • <i>within a short period of time</i> • <i>gradually</i>
-------------------------------------	--	--------------------	---

I. The theory of evolution can be described as	<ul style="list-style-type: none"> • <i>adaptation of organisms caused by environmental change</i> • <i>changes in organisms to meet the needs of their environment</i> • <i>the coexistence between human and dinosaurs</i> • <i>selection of useful characteristics of organisms</i> • <i>different reproductive rates among a population of organisms</i>
--	---

J. Scientific knowledge	<ul style="list-style-type: none"> • <i>is undermining religious schools of thought</i> • <i>is unchanging</i> • <i>is influenced by scientists' philosophical assumptions</i> • <i>develops over time</i>
-------------------------	--

- | | |
|------------|--|
| K. Science | <ul style="list-style-type: none"> • <i>involves truth and certainty</i> • <i>is related to the natural world</i> • <i>requires the rejection of supernatural being(s)</i> • <i>is totally objective</i> |
|------------|--|

- | | |
|---|---|
| L. Evolution cannot be scientifically accurate because it | <ul style="list-style-type: none"> • <i>contradicts to the second law of thermodynamics</i> • <i>contains weak aspects</i> • <i>lacks scientifically valid support</i> • <i>is not repeatable in the laboratory</i> • <i>is not testable in the laboratory</i> • <i>is not falsifiable</i> • <i>cannot be observed</i> • <i>provides no convincing evidence</i> • <i>contradicts to the biblical account of creation</i> • <i>cannot be proven</i> • <i>depends too much on chance</i> • <i>is based on a philosophy of atheism</i> • <i>is only a theory which is still uncertain</i> |
|---|---|

Appendix E: A formal letter sent to the school participant



To whom it may concern

I am Pratchayapong Yasri, a second year PhD student in Education at the University of Glasgow, conducting a research project entitled *Views of the relationship between science and religion and their implications for student learning of evolutionary biology*. This project aims to ask students' perceptions and understanding about science, religion and aspects of evolution education by using a questionnaire. It targets to M.4, M.5 and M.6 students who have taken Science-Mathematics programme. I therefore would like to ask for your permission to gain access to the students in your school.

I can confirm that the name of your school, its identification, as well as the name of student participants will be kept confidentially and anonymously in my written reports. All returned questionnaires will be kept securely and destroyed after my graduation in 2013.

Your cooperation will be greatly appreciated.

Sincerely,

Pratchayapong Yasri

Interdisciplinary Science Education, Technologies and Learning (ISETL)

<http://www.gla.ac.uk/faculties/education/informationforstaff/rktg/isetl/>

School of Education

College of Social Sciences

University of Glasgow

11 Eldon Street

Glasgow, G3 6NH

United Kingdom

Appendix F: Plain Language Statement



University
of Glasgow | School of
Education

Plain Language Statement

1. Research title

I'm Mr Pratchayapong Yasri, a second year PhD student in Education at the University of Glasgow, writing to you an invitation to my research project entitled *Views of the relationship between science and religion and their implications for student learning of evolutionary biology*. This project is under the supervision of Dr Rebecca Mancy

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. What are the purposes of the study?

This study aims to investigate (a) students' perceptions on the role of science and religion, how they can be related and how they impact on their understanding of the origins of life, (b) students' understanding and acceptance of evolutionary biology and its evidence, (c) students' learning approaches to evolution, and (d) motivations underlying the aspects mentioned

4. Why have I been chosen?

You are being approached because you are a high school student of Bangkok Christian College who have undertaken biology courses and/or evolution in particular.

5. Do I have to take part?

No. Your participation is voluntary. Although you decide to take part in this research, you are able to withdraw your participation at any time.

6. What will happen to me if I take part?

If you agree to take part in this research, you will be given a questionnaire asking your perception and understanding about science, religion and evolution education. It will take approximately 45 minutes to complete the questionnaire.

7. Will my taking part in this study be kept confidential?

Yes, of course. There is no need to provide your identity in the questionnaire so that you will be unable to be identified. In addition, the returned questionnaire will be kept in locked filing cabinet at the University of Glasgow. At the end of my study, all of returned questionnaires will be shredded.

8. What will happen to the results of the research study?

The results will be analysed by statistical tools as well as qualitative protocols. The research data will be typed up as a PhD dissertation, journal articles, conference papers and other academic purposes which you can be accessible to you (if required).

9. Who is organising and funding the research? (If relevant)

This research is organised by me, Mr Pratchayapong Yasri, through the University of Glasgow, funded by the Royal Thai Government. It is under the supervision of Dr Rebecca Mancy, the main supervisor, and Dr Shagufta Chandi, a co-researcher.

10. Who has reviewed the study?

Apart from the names of the people mentioned above, this research has been reviewed and approved by ethics committees of the School of Education, the College of Social Sciences, the University of Glasgow.

11. Contact for Further Information

If you have any other questions about the research project, you can contact me (Mr Pratchayapong Yasri) directly by phone on (+44) 777 590 8744 or by email on p.yasri.1@research.gla.ac.uk. You may also contact my supervisor (Dr Rebecca Mancy) on rebecca.mancy@glasgow.ac.uk

If you have any concerns about ethical issues of the conduct of the research project, you can direct to the College of Social Sciences Ethics Officer by contacting Dr Georgina Wardle at georgina.wardle@glasgow.ac.uk

Appendix G: Dichotomous key for identifying the relationship between science and religion

1.	Science and religion are incompatible	Go to 2
	Science and religion are compatible	Go to 4
2.	One explanation is better than the other	Go to 3
	No clear decision is made	<i>Compartment</i>
3.	Science trumps religion (only science is true)	<i>Conflict: STR</i>
	Religion trumps science (only religion is true)	<i>Conflict: RTS</i>
4.	Science and religion deal with separate realities	Go to 5 (contrast)
	Science and religion deal with one single reality	Go to 6 (consonance)
5.	Science and religion address different questions	<i>Contrast: Different Questions</i>
	Science and religion construct knowledge differently	<i>Contrast: Different Methods</i>
6.	Science and religion deal with the same domain	<i>Coalescence</i>
	Science and religion deal with different domains	<i>Complementary</i>

The first criterion divides compatible from incompatible. The second and the third criteria are used to distinguish the two subcategories of the *Conflict* view and the *Compartment* view. The fourth criterion separates *Contrast* from *consonance*. The two ways of separating science from religion according to the *Contrast* view are distinguished in the fifth criterion. Finally, the sixth criterion distinguishes between *Coalescence* and *Complementary* based on their perceived domain(s) within the single reality

Appendix H: Student levels of agreement on the different views of the relationship between science and religion (N = 327)

Views on science-religion	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
Compartment	11.6%	34.6%	30.6%	14.7%	8.6%
Conflict – STR	8.3%	20.5%	38.2%	20.2%	12.8%
Conflict – RTS	5.8%	11.6%	45.6%	29.1%	8.0%
Contrast - questions	23.2%	41.9%	23.5%	7.0%	4.3%
Contrast – methods	11.9%	38.8%	33.3%	9.5%	6.4%
Coalescence	15.0%	43.7%	27.2%	8.3%	5.8%
Complementary	26.6%	50.2%	19.0%	3.4%	0.9%

Appendix I: The key for scoring student responses to MUSE (all incorrect items are crossed out)

A. Complex structures (e.g. human eyes, bacterium flagellum), biological processes (e.g. blood clotting, DNA replication) and various species (e.g. humans, insects) are the results of processes involving

- *natural selection*
- ~~*intelligent design*~~
- *evolutionary processes*
- ~~*chance*~~
- ~~*randomness*~~

B. Many scientists and members of the scientific community

- ~~*doubt if*~~
- *accept that*
- *agree that*
- ~~*disagree that*~~
- ~~*cannot explain*~~

evolution occurs.

C. Darwinian evolution is an explanation of the origin of

- ~~*species from non-living particles*~~
- *species from ancestral species*
- ~~*the first living things*~~
- ~~*life on earth*~~
- ~~*humans from monkeys*~~
- *species by means of natural selection*

- D. Organisms existing today
- *have come into being over millions of years*
 - ~~*were created in six days*~~
 - ~~*were created between 6000-10000 years ago*~~
 - ~~*have been created over millions of years*~~
 - *have developed from their early forms over millions*

- E. The theory of evolution is based on
- ~~*speculation*~~
 - *scientific research*
 - ~~*faith*~~
 - ~~*popularity*~~
 - ~~*revelation*~~

- F. The theory of evolution is developed from
- *factual historical data*
 - ~~*ambiguous data*~~
 - *laboratory data*
 - ~~*untestable assumptions*~~

- G. Evolution is about
- ~~*changes in individuals*~~
 - *changes in populations*
 - *a dynamic process*

H. Modern humans are the product of	<ul style="list-style-type: none"> • evolutionary processes • design • chance processes • random processes • directionless processes • purposeless process • adaptation of monkeys 	that have occurred	<ul style="list-style-type: none"> • over millions of years • within a short period of time • gradually
-------------------------------------	---	--------------------	---

I. The theory of evolution can be described as	<ul style="list-style-type: none"> • adaptation of organisms caused by environmental change • changes in organisms to meet the needs of their environment • the coexistence between human and dinosaurs • selection of useful characteristics of organisms • different reproductive rates among a population of organisms
--	--

J. Scientific knowledge	<ul style="list-style-type: none"> • is undermining religious schools of thought • is unchanging • is influenced by scientists' philosophical assumptions • develops over time
-------------------------	--

K. Science

- ~~involves truth and certainty~~
- ~~is related to the natural world~~
- ~~requires the rejection of supernatural being(s)~~
- ~~is totally objective~~

L. Evolution cannot be scientifically accurate because it

- ~~contradicts to the second law of thermodynamics~~
- ~~contains weak aspects~~
- ~~lacks scientifically valid support~~
- ~~is not repeatable in the laboratory~~
- ~~is not testable in the laboratory~~
- ~~is not falsifiable~~
- ~~cannot be observed~~
- ~~provides no convincing evidence~~
- ~~contradicts to the biblical account of creation~~
- ~~cannot be proven~~
- ~~depends too much on chance~~
- ~~is based on a philosophy of atheism~~
- ~~is only a theory which is still uncertain~~

Appendix J: License Agreement between the author and Springer

SPRINGER LICENSE TERMS AND CONDITIONS

Mar 28, 2014

This is a License Agreement between Pratchayapong Yasri ("You") and Springer ("Springer") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by Springer, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	3357621327031
License date	Mar 28, 2014
Licensed content publisher	Springer
Licensed content publication	Science and Education
Licensed content title	Relating Science and Religion: An Ontology of Taxonomies and Development of a Research Tool for Identifying Individual Views
Licensed content author	Pratchayapong Yasri
Licensed content date	Jan 1, 2013
Volume number	22
Issue number	10
Type of Use	Thesis/Dissertation
Portion	Full text
Number of copies	1
Author of this Springer article	Yes and you are the sole author of the new work
Order reference number	Yasri_Thesis_2014
Title of your thesis / dissertation	Views of the Relationship between Science and Religion and their Implications for Student Learning of Evolutionary Biology
Expected completion date	Mar 2014
Estimated size(pages)	271
Total	0.00 GBP
Terms and Conditions	

Introduction

The publisher for this copyrighted material is Springer Science + Business Media. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and

Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your Rightslink account and that are available at any time at <http://myaccount.copyright.com>).

Limited License

With reference to your request to reprint in your thesis material on which Springer Science and Business Media control the copyright, permission is granted, free of charge, for the use indicated in your enquiry.

Licenses are for one-time use only with a maximum distribution equal to the number that you identified in the licensing process.

This License includes use in an electronic form, provided its password protected or on the university's intranet or repository, including UMI (according to the definition at the Sherpa website: <http://www.sherpa.ac.uk/romeo/>). For any other electronic use, please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com).

The material can only be used for the purpose of defending your thesis, and with a maximum of 100 extra copies in paper.

Although Springer holds copyright to the material and is entitled to negotiate on rights, this license is only valid, subject to a courtesy information to the author (address is given with the article/chapter) and provided it concerns original material which does not carry references to other sources (if material in question appears with credit to another source, authorization from that source is required as well).

Permission free of charge on this occasion does not prejudice any rights we might have to charge for reproduction of our copyrighted material in the future.

Altering/Modifying Material: Not Permitted

You may not alter or modify the material in any manner. Abbreviations, additions, deletions and/or any other alterations shall be made only with prior written authorization of the author(s) and/or Springer Science + Business Media. (Please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com))

Reservation of Rights

Springer Science + Business Media reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction, (ii) these terms and conditions and (iii) CCC's Billing and Payment terms and conditions.

Copyright Notice:Disclaimer

You must include the following copyright and permission notice in connection with any reproduction of the licensed material: "Springer and the original publisher /journal title, volume, year of publication, page, chapter/article title, name(s) of author(s), figure number(s), original copyright notice) is given to the publication in which the material was originally published, by adding; with kind permission from Springer Science and Business Media"

Warranties: None

Example 1: Springer Science + Business Media makes no representations or warranties with respect to the licensed material.

Example 2: Springer Science + Business Media makes no representations or warranties with respect to the licensed material and adopts on its own behalf the limitations and disclaimers established by CCC on its behalf in its Billing and Payment terms and conditions for this licensing transaction.

Indemnity

You hereby indemnify and agree to hold harmless Springer Science + Business Media and CCC, and their respective officers, directors, employees and agents, from and against any and all claims arising out of your use of the licensed material other than as specifically authorized pursuant to this license.

No Transfer of License

This license is personal to you and may not be sublicensed, assigned, or transferred by you to any other person without Springer Science + Business Media's written permission.

No Amendment Except in Writing

This license may not be amended except in a writing signed by both parties (or, in the case of Springer Science + Business Media, by CCC on Springer Science + Business Media's behalf).

Objection to Contrary Terms

Springer Science + Business Media hereby objects to any terms contained in any purchase order, acknowledgment, check endorsement or other writing prepared by you, which terms are inconsistent with these terms and conditions or CCC's Billing and Payment terms and conditions. These terms and conditions, together with CCC's Billing and Payment terms and conditions (which are incorporated herein), comprise the entire agreement between you and Springer Science + Business Media (and CCC) concerning this licensing transaction. In the event of any conflict between your obligations established by these terms and conditions and those established by CCC's Billing and Payment terms and conditions, these terms and conditions shall control.

Jurisdiction

All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in The Netherlands, in accordance with Dutch law, and to be conducted under the Rules of the 'Netherlands Arbitrage Instituut' (Netherlands Institute of Arbitration). *OR:*

All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in the Federal Republic of Germany, in accordance with German law.

Other terms and conditions:

v1.3

If you would like to pay for this license now, please remit this license along with your payment made payable to "COPYRIGHT CLEARANCE CENTER" otherwise you will be invoiced within 48 hours of the license date. Payment should be in the form of a check or money order referencing your account number and this invoice number RLNK501263405. Once you receive your invoice for this order, you may pay your invoice by credit card. Please follow instructions provided at that time.

Make Payment To:
Copyright Clearance Center
Dept 001
P.O. Box 843006
Boston, MA 02284-3006

For suggestions or comments regarding this order, contact RightsLink Customer Support: customercare@copyright.com or +1-877-622-5543 (toll free in the US) or +1-978-646-2777.

Gratis licenses (referencing \$0 in the Total field) are free. Please retain this printable license for your reference. No payment is required.
